BUILDING AN ENGINEERING CAREER

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BY

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BUILDING AN ENGINEERING CAREER

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PREFACE TO THE SECOND EDITION

The revision of this book is necessitated by developments in the sciences and in the relations of the engineering profession to society and is prompted by the wishes of those who have found the volume useful as a text in freshman college classes and in vocational-guidance programs in secondary schools. Suggestions from a number of users were sought and have been gratefully incorporated so far as practicable in the new edition. Significant innovations occasioned by the Second World War have been taken into account.

The growing number of specialties loosely called "engineering" makes it ever more imperative to keep clear the main trunk-line approaches to the profession. The problems have been assembled in an appendix for better group illustration, and a separate chapter on Mining and Metallurgy has been inserted to clarify the scope of those branches. A more extensive outline of professional occupations has been included with a view to broadening the student's vocational outlook as he is confronted with the choice of his career. A brief list of visual aids has been appended.

Additional emphasis has been placed on the social significance of engineering with its corollaries of intellectual satisfactions, companionable enjoyment, and effective citizenship, in order that the student may not pass by these incidental values as he proceeds in his course. The revision contemplates the widening functions and responsibilities of engineers in modern society, which increase the importance of an informed selection for those who undertake a career in this profession.

CLEMENT C. WILLIAMS.

MADISON, WIS.,
February, 1946.

PREFACE TO THE FIRST EDITION

In order to enable engineering students to enter upon their study advantageously and to work efficiently from the beginning, the author has been conducting a course during the past six years aimed at both orientation and motivation, with the following specific objectives in view:

1. To give a preview of the engineering profession as to its character and its relation to social organization in order to aid the student in his choice of a vocation.

2. To assist the student at the outset in adopting efficient study methods and in forming orderly mental habits, particularly with reference to technical subject matter.

3. To indicate the quantitative and creative nature of an engineer's mode of thinking, using to this end problems that involve engineering concepts but no advanced mathematics.

4. To afford a background by means of a historical synopsis of the preceding story of engineering that will enable the student in retrospect to perceive the slow development through all previous history as compared with the tremendous acceleration of the last century and, in prospect, to glimpse the unpredictable expansion of engineering achievement destined to follow modern discoveries in physical science.

5. To conserve and cultivate as a motivating influence the student's initial interest in engineering during that disappointing period of his assignment to fundamental, although to him irrelevant, subjects, and to enable him to view his course as a unified engineering project.

6. To introduce the student to the vocabulary of engineering by means of narrative rather than by technical definitions.

7. To show the student a layout view of the engineering curriculum and profession as the general plan from which he will build an engineering career.

8. To inculcate, by means of a recital of engineering triumphs, a will to achieve in study and in the profession.

9. To call attention to the ethical and cultural ideals of the profession and to the desirability of forming ethical attitudes as well as efficient mental habits.

From this course, the present textbook has been developed.

The need of orientation as to course and career has been widely recognized, and, at various colleges, lecture series and problem courses have been instituted to accomplish the desired instruction. While the other objectives have been sometimes urged, few specific attempts have been made toward their realization. That the above purposes can be attained in a gratifying degree through the instrumentality of a study and conference course has been demonstrated by our experience. Needless to state, instruction by professors of mature experience contributes potently to the success of the course. Assignment of reviews and readings in current periodicals has been found a helpful supplement in stimulating and sustaining interest.

The problems proposed involve obvious relationships so that the student should be able to solve them without specific textual explanation; hence no attempt has been made to include a discussion of the specific theory involved. They are intended to provoke questions and to constitute exercises in elementary engineering thinking.

Thanks are due to B. J. Lambert, Head of the Department of Civil Engineering; E. B. Kurtz, Head of the Department of Electrical Engineering; H. O. Croft, Head of the Department of Mechanical Engineering; E. L. Waterman, Professor of Sanitary Engineering; and R. M. Barnes, Associate Professor of Industrial Engineering, all of the State University of Iowa, for their cooperation in conducting sections of the course and for helpful suggestions as to its content; also to H. L. Olin, Professor of Chemical Engineering, who aided in the matter that pertains to chemical engineering.

CLEMENT C. WILLIAMS.

IOWA CITY, IOWA,
February, 1934.

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CHAPTER I

VOCATIONS AND PROFESSIONS

Introduction. A young man entering college with a view to preparation for a specific life work looks forward to his chosen vocation as a promised land into which he will enter and conquer. It is not possible to lead him to a lofty Pisgah and point out all of the difficulties involved in his entrance to his promised land and in its conquest. In his career he may expect minor defeats as well as minor triumphs; he should be satisfied if his career leads ultimately to success. An understanding of some of the practices and principles found by others to be reliable and true will prevent many of the lesser mistakes with their consequent disappointments and make final victory the more certain.

Nowhere else in one's career is instruction as to procedures likely to be more helpful than in matters pertaining to choice of vocation and planning a college course, for there is probably no other point at which one's uncertainty is more pronounced, when counsel can be given with more assurance, and when the returns from wise planning will be greater. To give careful thought, therefore, to coordinating, harmonizing, and unifying one's college course with one's life plan is obviously the part

of prudence, and time may well be devoted to doing this matter in an orderly and thoroughgoing manner.

Definitions. Discrimination in the use of certain terms related to professions and vocations in general will contribute to a clearer grasp of matters involved in the choice of a profession and in the preparation to enter into professional practice. The work that people perform for hire may involve personal service or it may pertain to the production of something of economic value; the most general term to apply to all such work is *gainful occupation,* which signifies any kind of work done for a compensation. Gainful occupations may be divided into two groups: (1) *unskilled labor* and (2) *vocations.*

A large proportion of all gainful occupations consists of unskilled labor, either routine or under immediate direction, the doing of which requires neither skill nor mental acumen but merely physical capabilities and such elemental thinking as may be involved in performing the work. For "unskilled labor," neither special aptitude nor training is required.

The term *vocation,* or *calling* (from Latin, *vocatus* = called), is applied to occupations in which some peculiar qualifications which the individual may possess appear *to call* him to do that special kind of work. The term *vocation* usually implies special preparation of some sort for doing the work involved and is commonly used to denote all occupations other than unskilled labor. Vocations include trades or crafts, clerking and secretarial work, business, arts, and professions.

A *trade* or *craft* is a manual skill within a limited range of operations which requires a special training, usually in the form of instruction as an *apprentice* from a *master craftsman.*

Clerking and *secretarial* work represents a skilled vocation concerned with routine business transactions and the keeping of records.

Business is commonly applied to the occupation of merchandising, usually buying and selling, either as a principal for profit or as an agent for commission. Such merchandising may comprise goods, securities, real estate, property rights, or services.

An *art* is a vocation in which one does things with a special skill that is the result of the accumulated experience of workers in the field. An *artist* is one who, with special talent, produces works for intellectual and emotional satisfactions and is said to practice a *fine art*. An *artisan* applies a handicraft of a more or less intricate sort in producing articles from baser materials and is said to practice an *applied art*.

A *profession* is an intellectual pursuit that consists in giving counsel for a compensation by one who *professes* competency. Such competency may have various degrees of public recognition and certification, such as a professional-school diploma or a license by a state board of authorized examiners. The counsel may be given individually, or it may be given through the agencies of organized society. Thus a physician gives counsel concerning health, a lawyer concerning legal rights, a minister concerning spiritual welfare, a teacher concerning education, an accountant concerning adequacy of records, while an engineer gives counsel concerning public works, technical procedures, and industrial operations.

The term *career*, broader than occupation, denotes not only one's work but one's whole course of life.

Success in one's career is attained when one, with a consciousness of having served mankind worthily,

acquires a competence and receives the approbation of one's fellow workers.

Desirable Features of a Vocation. What one may most desire in one's vocation depends upon the individual, but a few of the more obvious features usually sought may be mentioned.

1. The aptitudes required should be such as one possesses so that one may achieve creditably. For example, one should not seek to be a musician if one has no ear for tone nor sense of rhythm.

2. The nature and obligations of the vocation should be in harmony with rather than repugnant to one's tastes, in order to enjoy the work. Unless one enjoys one's work, one will be unhappy regardless of how great the pecuniary rewards may be.

3. One should choose a vocation that is waxing more important in the world's affairs rather than waning, in order that one may not find the investment in preparation to diminish in value.

4. The vocation should permit a satisfactory private and home life. A vocation which requires one to compromise one's ideals or which incurs undue annoyance from any source may not permit the enjoyment of private life.

5. A reasonable amount of social recognition for achievement in the vocation is important, for it is a characteristic of human nature to desire standing amongst one's fellow men.

6. The earnings from a vocation should be sufficient to permit a satisfactory standard of living and, through reasonable frugality, to provide a competence for old age.

7. Security of employment is more important than large earnings. Large earnings frequently accompany hazard of continuity in employment, while one's vocation should contemplate a life program.

8. The fear of a vocation's being overcrowded should usually be dispelled, for there is always room for the capable in any calling that worthily serves mankind; at the same time, the incompetent will suffer from competition in any field of endeavor. When Benjamin Franklin proposed to get married, his prospective father-in-law objected to him because he was in an overcrowded vocation, there being another printer already in the colony.

Entrance to a Profession. Practically all professions had their origins in *apprenticeships* and *guilds*, in which

the beginner served for a period at little or no wages, assisting intimately in the practice of a recognized practitioner. After the period of apprenticeship expired, the beginner was accredited as a qualified member of the guild by the master. The procedure was similar to learning any trade, but with the development and utilization of scientific knowledge, some of the guilds, instrument makers, millwrights, etc., appropriating to their practice the usable principles of mathematics and mechanics, and the results of scientific investigations, grew into the profession of engineering.

There are still many technical arts, or *subprofessional* vocations, such as drafting, surveying, machine work, wiring, plant operation, technician's and lineman's operations, which serve engineering and which frequently offer an avenue by which the young graduate may find a place in the profession.

The employment of apprentices under the guild system became so profitable to certain master craftsmen of reputation that their procedures in training their assistants became virtual schools. Such training practices were the forerunners of the modern professional schools, which have entirely supplanted the former guild training.

While the way is still open legally to enter most professions by the apprenticeship route, the approved and most advantageous entrance is by way of a college course followed by a period of subprofessional assistanceship.

The proportions of men at different ages gainfully employed, the numbers in school, and those entering various kinds of employment in the United States are shown in Fig. 1. The lower part of the diagram indicates numerical distribution, while the upper part shows relative proportions. Although entering a small voca-

tional group, such as a profession, does not avoid competition, it changes the nature of competition so that one's employment is under one's own control to an

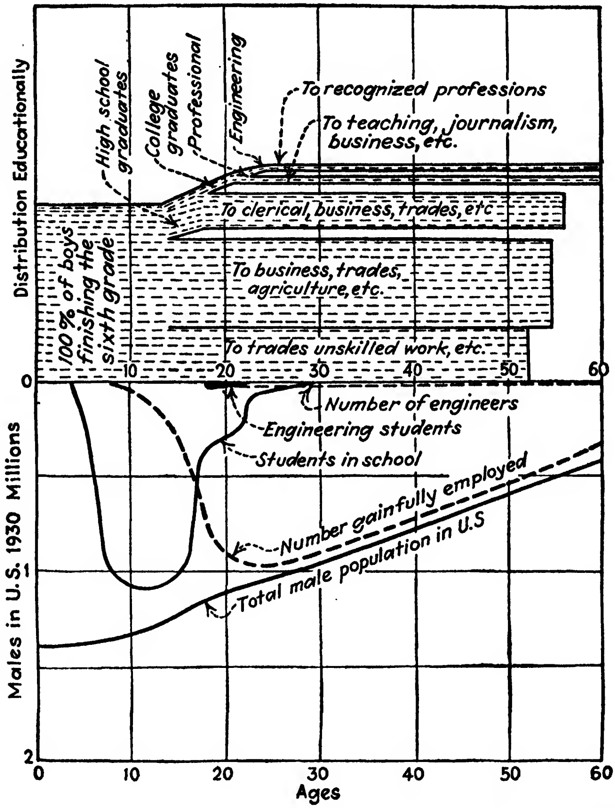


FIG. 1.—Distribution of male population in the United States. Education is the most potent factor in reducing vocational competition.

extent and not determined by freakish economic forces and winds of fortune over which one has no influence.

Vocational Distribution. The men gainfully employed in the United States are distributed to the professions approximately as indicated below:

Categories	Total	Entering annually
Gainfully employed, male	38,000,000	1,200,000
Professions and semiprofessions	1,900,000	60,000
Lawyers	240,000	9,000
Physicians	270,000	5,000
Dentists	120,000	2,000
Architects and architectural engineers	20,000	750
Engineers	320,000	14,000
Chemical	17,000	3,000
Civil	90,000	1,800
Electrical	60,000	2,500
Mechanical	95,000	5,000
Mining and metallurgical	12,500	900

The profession of engineering has increased annually by about 9,000, or 4½ per cent, since 1920. During this period, the population of the United States has increased only 1¼ per cent per year. Owing to the rapid developments in technology, the demand for engineers grows more than three times as fast as the population and considerably exceeds the numbers graduating from colleges of engineering.

The distribution of engineers to different sources of employment is shown in the table on page 8. In the decades subsequent to the First World War, there has been a perceptible trend of engineers, especially civil engineers, from private to governmental employment.

Personal Qualities That Promote Professional Success. A summary of replies to an extensive inquiry made among practicing engineers indicated that certain personal qualities promote professional success quite as much as do technical ability and training. The student should give thought to these, therefore, and strive to improve his qualification in respect thereto. In general,

such qualities as listed below are universally recognized as contributing to real success in any vocation.

Character, meaning honesty, moral courage, sense of honor, reliability, integrity, and good citizenship, counts for most as an essential element of success.

SOURCES OF ENGINEERING EMPLOYMENT*
(Percentages of total number, 1930)

Engineers	Private firm	Federal government	State and county	City and other	Education	Independent practice	Non-engineering
Chemical:							
Ages over 47..	57	3	1	3	12	10	14
Ages 23–27...	74	2	2	2	6	13	1
Civil:							
Ages over 47..	42	7	13	17	5	6	10
Ages 23–27...	49	12	19	12	4	3	1
Electrical:							
Ages over 47..	63	2	2	5	10	6	12
Ages 23–27...	82	2	1	2	5	8	1
Mechanical:							
Ages over 47..	67	3	1	3	10	7	9
Ages 23–27...	84	3	1	1	5	5	1
Mining and metallurgical:							
Ages over 47..	45	5	1	2	10	14	23
Ages 23–27...	81	3	4	1	5	4	2

* *U. S. Dept. Labor Bull.* 682.

Understanding of men, comprising how to get along with superiors, equals, and subordinates, how to meet and mingle with men informally and formally, how to recognize personal traits and aptitudes, and to organize and direct men, all of which is sometimes grouped as executive ability, is the second factor.

Good judgment, including common sense, sense of proportion, broad view, and good taste in dress, deportment, and conversation, is a third item.

Industry, implying application, persistence, promptness, efficiency, and general attention to duty is the fourth.

Initiative, signifying enterprise, resourcefulness, self-confidence, imagination, quickness of action, forcefulness, decision, and general alertness is the fifth.

Courtesy, denoting considerateness, generous recognition of the rights and an appreciation of the virtues of others, good manners, compliance with proper social forms, forbearance in such matters as practical jokes, caustic remarks, cutting witticisms, and gossip, and even a conscious effort to be agreeable, is the sixth.

Health is so important that perhaps it should not be mentioned last. Those who have it should adopt unswervingly those habits of living that will conserve it, and those who do not have it should seek the remedial counsel that will ensure it.

The importance of these personal qualities is readily recognized without argument or elaboration, and the advisability of seeking improvement therein need not be illustrated by instances and examples.

Career Occupations. A summary of the principal occupations of the professional sorts for which academic preparation is commonly necessary in a planned career will aid a young man in finding his vocational interest and in making a choice. The following alphabetical titles are taken chiefly from the Dictionary of Occupations of the U. S. Department of Labor:

Professional Occupations.

1. Accountants: general accountant, public accountant, tax accountant, auditor, comptroller.
2. Actor: character man, heavy, juvenile (amusement), leading man, comedian, impersonator, dramatic reader, director, manager.
3. Architect: building architect, landscape architect, marine architect.

4. Artist: painter, glass stainer, cartoonist, sculptor, commercial artist.

5. Author: biographer, essayist, humorist, fiction, playwright, poet, publicist. Movies and radio: adapter, collaborator, continuity writer, news editor, scenario editor, film editor, gag writer, script writer, title writer, news commentator.

6. Editor: book editor, city editor, departmental (amusement, art, book, club, fashion, feature, financial, household, junior, marine, music, radio, real estate, screen, society, sports, stage, Sunday), managing editor, news editor, editorial writer, telegraph editor, magazine editor, trade-journal editor, publicity man, public-relations man, correspondent.

7. Chemists: vinous liquors, canning and preserving, confections, dairy, food, nutritional, pharmaceutical, paint and varnish, petroleum, textile, wood preservation.

8. Clergymen: minister, pastor, rector.

9. Educator: college president, professor, dean, director of extension or other division, secondary school, elementary school.

10. County agent and demonstrator: Four-H agent, agricultural agent.

11. Dentists: dental surgeon, exodontist, orthodontist, pediodontist, prosthodontist.

12. Engineers, chemical: food products, sugar manufacture, packing, gas manufacture, petroleum, heavy chemicals, plastics and fabrics, paper, paint, ceramics.

13. Engineers, civil: construction, city planning, estimating, highway, hydraulic, insurance, irrigation, railway, sanitary, structural, airport.

14. Engineers, electrical: design, lighting, line construction, power plant, radio, telephone, sound (motion pictures).

15. Engineers, industrial: factory layout, safety, time study.

16. Engineers, mechanical: air conditioning, automotive, aeronautic, combustion, gas distribution, heating, machine and tool design, marine, plant, refrigeration, railway mechanical, ventilating.

17. Engineers, mining: coal, metal, petroleum, mine operator. Metallurgical: iron and steel, heat-treatment.

18. Lawyers: attorney, counselor, solicitor, claim attorney, corporation lawyer, criminal lawyer, admiralty lawyer, patent attorney, district attorney, judge, magistrate.

19. Librarians: cataloguer, bibliographer, manager.

20. Musicians: soloists, composers, concert artists, conductors.

21. Pharmacists: apothecary, pharmaceutical manufacturer.

22. Physicians: doctor, aurist, cardiologist, dermatologist, gynecologist, health officer, laryngologist, neurologist, obstetrician, oculist, orthopedist, pathologist, proctologist, psychiatrist, rhinologist, roëntgenologist, surgeon, urologist.

23. Social workers: case consultant, child welfare, community service, court worker, settlement worker, traveler's aid, recreation.

24. Statisticians: actuary, economic, financial, social analysis.

25. Veterinarians: general, small-animal specialist, pathologist.

26. Teachers: elementary, secondary, college, vocational.

27. Miscellaneous: forester, curator, archeologist, clinical psychologist, cytologist, bacteriologist, plant pathologist, geologist, meteorologist, agronomist, acoustician, seismologist, personnel director.

Typical semiprofessional vocations associated with engineering include the following (1) draftsmen: detailers, tracers, cartographers, die designers; (2) laboratory technicians: cement tester, steel sampler, oil tester, instrument tester; (3) radio operators; (4) surveyors: land surveyor, mine surveyor, timber surveyor; (5) inspectors: machine, masonry, steel; (6) salesmen: equipment, materials, supplies.

Many skilled trades are closely related to engineering and may be followed by those who are technically inclined but who do not prepare for professional careers. They include operators of special machines, electroplaters, machinists, sheet-metal workers, welders, heat-treaters, ore dressers, electricians, steam fitters, and others.

In summary, the U.S. Department of Labor lists about 245 types of vocations grouped as follows: professions 25, semiprofessions 15, managerial 15, clerical 35, sales 15, and skilled labor 135.

Aptitudes. The word aptitude denotes a complex mental trait, the capacity to achieve in the designated activity. There is no direct method available for meas-

uring aptitude; it can be estimated only by inference from tests of various kinds and comparison with the average performance of many persons. The object of the tests is to discover the degree of relationship or response of *internal qualities* of the mind to *external*

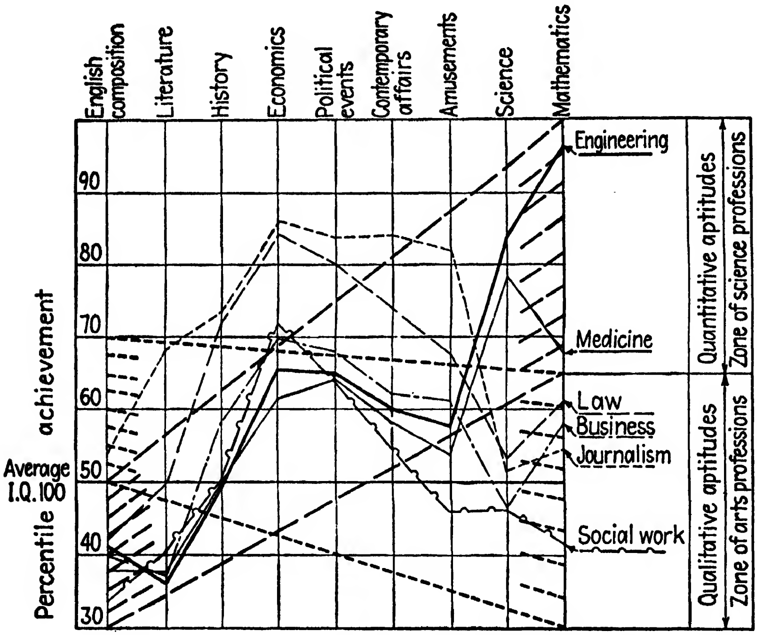


FIG. 2.—Percentile scores of college sophomore students related to professional goals. Note the wider spread in the mathematics-science than in the language-history scores. (*Regrouped from the* 1939 *report of the Sophomore Testing Committee, American Council on Education.*)

requirements of environment. If those internal qualities fit or match the external requirements, the individual has an aptitude for the vocation involved.

The quest, therefore, comprises two parts: (1) identifying those internal capacities of the individual and (2) analyzing the external requirements for various specific vocations.

Although aptitudes are infinitely varied in detail, test performances indicate two types, *viz.*, (1) language-history (qualitative) aptitudes and (2) mathematics-science (quantitative) aptitudes. These are somewhat complementary of each other, as are the two eyes, two ears, or two mental responses (rational and emotional). Figure 2, which groups the performance of the male students in the 1939 National College Sophomore Tests[1] relative to their professional goals, indicates these two sorts of aptitudes. Although in most capable people these two kinds of qualities are fairly balanced, the disparity in some amounts to peculiar genius. They are analogous to right- or left-handedness; as some are ambidextrous, so some are ambi-apt. This simplification of aptitudes into two broad channels of capabilities omits special talents, such as for music and other fine arts; it applies to normal college youth. Scaled score 50 is what the "average American" with an I.Q. of 100 would make on graduation from high school.

All such data represent averages from which any individual case may vary widely. The old saying, "a square peg in a round hole," is more vivid than valid; the hopeless rigidity of the concept is as erroneous as it is discouraging. Within limits, aptitudes will develop and adjust if the will is sufficient; overanxiety to find the one occupational niche is needless and futile. Most people of ability and character do at least fairly well whatever their job.

Choosing a Profession. To enter a profession, one must make a specific choice; for one cannot drift into a profession as many do into trades, businesses, and other vocations. That choice should depend on (1) one's aptitudes and (2) one's interests. Since the professions

[1] *Jour. Exp. Education,* March, 1940.

total only about 5 per cent of the male population, they will be found to be accessible chiefly to those in the top third of their high-school class. To follow a profession requires an ability to learn from books; hence a student in the lower third of his high-school class would be well advised to choose a vocation other than a profession. Individual aptitudes are not sharply differentiated according to occupational patterns and hence are not specifically identifiable in terms of vocations. The two general types of aptitudes, *viz.*, qualitative and quantitative, are guiding beacons. For a quantitatively apt person to select a qualitative-type profession would be akin to a left-handed person taking a right-handed job; he would be handicapped, even though by force of will he might be successful. One should choose a profession within the range of his aptitudes: accountant, architect, chemist, engineer, physician, statistician, etc., for the quantitative type, or actor, author, editor, lawyer, teacher, etc., for the qualitative type where the differentiation is marked.

Interests likewise are of two types: (1) conscious interests, those which are uppermost in one's thoughts, and (2) subconscious interests, the condensed accumulation of temporary interests. The latter may be the more reliable gage of permanent interest, since the former may reflect chiefly the recency of enjoyable observation or reading. Permanent interests are indicated by the kind of news and magazine articles one most enjoys and by what things one knows most about. There is a correlation between one's accumulated knowledge and one's permanent interests resulting from the principle that things instinctively adhere to one's memory somewhat in proportion to one's interest. Interest and aptitude are interrelated, since one is likely to find interest in a

subject that he can grasp and to lack interest in what baffles him. Scholastic records, therefore, reflect both aptitude and interest and, if grouped into the two types of subjects, are vocationally significant.

Who Should Enter the Engineering Profession? To be successful and happy in engineering, one must have the abilities both intellectual and volitional to do the work involved and a taste, or liking, for that kind of work. If one has the ability requisite for one branch of engineering, one has the ability generally for any other branch as well, since the type of abilities is essentially the same for almost any branch that one might choose to enter.

As to *ability*, observations have rather clearly proved that, if a student has been successful with his mathematics—arithmetic, algebra, and geometry—and with his physics and chemistry in his preparatory school, in nearly all cases he has the ability to study and to practice engineering successfully. Mathematics is the most reliable single index of engineering ability. Observations indicate that a student who was in the lowest fifth of his class in mathematics in high school is seldom able to complete an engineering course in 4 years, while very few of those in the top fifth of their preparatory mathematics classes fail, on account of poor scholarship, to graduate on time in engineering courses.[1] Physics, chemistry, and English are also good indices of engineering ability but not so good as mathematics. Cleverness in the use of tools or in other manual exercises has practically no significance as an index of engineering ability, although it may indicate a liking for engineering. Mathematics is a good index because engineering thinking is of a quantitative or mathematical sort, and, there-

[1] *Jour. Soc. Promotion Eng. Education*, vol. 20, p. 475, 1930.

fore, a student may be guided fairly reliably in judging his engineering ability by his previous success with mathematics.

In deciding the second factor as to *taste*, or inclination, for engineering work,. if a student likes mathematics, physics, and chemistry, he will enjoy an engineering course in college and if he finds in himself an interest in buildings, bridges, public works, engines, machines, electrical devices, etc., he will in all probability enjoy the practice of engineering.

CHAPTER II

THE PROFESSION OF ENGINEERING

Definition of Engineering. Because of the diversity of considerations and operations included in the work of engineers, it is difficult to set the boundaries to the province of engineering through a definition. A definition that includes everything that has been labeled engineering would be so broad as to cover the entire realm of applied art, applied science, and applied economics. A definition that includes the great core of engineering and at the same time permits associated activities to fall within the fringes at the border lines may be stated: "Engineering is the scientific utilization of the forces and materials of nature in the design, construction, production, and operation of works for the benefit of man."

"Scientific utilization" involves a choice of method best suited to the desired end, requiring an expert knowledge of past experience and a creative ability to meet new situations, for in many cases the procedure is without precedent and the problem must be solved afresh. The results of scientific utilization should be reliability and economy.

The "forces" involved include those derived from heat energy from fuels through steam and internal-combustion engines, water falls, electricity, gravitation, wind pressure, buoyancy of water, mechanical action, radioactivity, magnetism, cohesion, etc.

The "materials" comprise iron, stone, timber, copper, water, rubber, composite materials, alloys, etc.

"Construction" embraces the erection of bridges, buildings, railroads, water systems, highways, and other forms of public and private works. "Production" means principally power generation and the manufacture of goods on an organized scale. "Operation" means organizing man power, funds, and procedures in carrying on industrial and utility enterprises. "Works" includes not only public works but factories, machines, and manufactured products as well.

The "benefit of man" means essentially supplying the economic needs of men, such as housing, transportation, communication, food, clothing, entertainment, and convenience, and implies a knowledge of economic organization of society, because the economic needs of the race are supplied through highly complex organization of production and distribution.

Origin of Terms "Engine" and "Engineer." According to the "New English Dictionary of Historical Principles," the term *engine* is derived through the old French from the Latin roots *in genere*, meaning to beget or to create, being closely akin to *engender*. The words *ingenious* and *ingenuity* are from the Latin roots and have related meanings. The Latin word *ingenium*, meaning a clever device, either an implement or a plan, may be considered more directly as the ancestral form of "engine."

In the early English, the word *engine* sometimes meant ingenuity, as in Chaucer's "Canterbury Tales" (1380), "A man hath sapiences three, memorie, engin and intellect." At that time also the word had the meaning of a mechanical contrivance, as when the monk Robert Brunne wrote (1300), "Geauntz sette them [the stones

of Stonehenge] on an hil full hey with engyns fulle queyntely." The word *engine* was early used in English as a verb also, meaning to plan or to contrive, in the identical sense as the Latin word *ingeniare.* Thus Poet Gower wrote in 1400, "With fair haste and great skill, of gold gifts that they have engined together," and Barlow (1609), "The most horrible design . . . that ever was engined." To engine a device, therefore, signified to plan it with acumen, and one who engined or contrived ingenious devices was, therefore, an engineer (engine + er), just as a contriver was one who contrived. The word was sometimes spelled *enginer,* as in Shakespeare's "Hamlet," "For 'tis the sport to have the enginer hoist with his own petar," or by Ben Jonson (1600), "He is a good enginer that alone can make an instrument to get preferment," but it was more frequently spelled *engineer.*

The word is of similar form in most of the European languages, *e.g.*, French, Dutch, Swiss, and German *ingenieur,* Spanish *ingenero,* and Italian *ingegnere,* and in all of these tongues the word means ingenious designer. Those who first took the name *engineer,* in England as well as in other countries, were designers and not machine or engine operators.

The word *engineer,* therefore, means an ingenious designer or planner, and only in a recent and local sense does it signify one who operates an engine, for which vocation *engineman* is more accurate and appropriate. This latter use of the word engineer is confined to the United States and almost entirely to the uneducated.

The Vocation of Engineering. As a vocation, engineering is a profession and involves to a greater or lesser degree the characteristics of a science, an art, and a business.

As a science, engineering requires a knowledge of the physical laws of nature and an acquaintance with the mechanical properties of the materials which the engineer must use. Mathematics, physics, chemistry, and mechanics are the physical sciences which most directly serve the engineer and he must be sufficiently versed in these to be able to use them reliably in his plans. Other sciences—biology, geology, and economics—also have a bearing on some of his work. Engineering is sometimes called *applied science*, but this term is unsatisfactory because there are other applied sciences and, furthermore, it includes many features of investigative science.

As an *art*, engineering is based on the accumulated experience of the past masters. The general procedure, the kinds of working tools best suited to a purpose, the capacities of tradesmen and their rates of working, the relative advantages of laborsaving machinery, and the proper organization of the working force are all matters primarily of experience.

As a *business*, engineering involves the selling of one's professional services advantageously. This aspect is particularly important in the work of the engineer engaged in private or consulting practice. He must be on the alert to learn where his services might be needed, and he must have a faculty for convincing industrial managers, boards of directors, city councils, and others that his services are adequate to their needs, without too blatantly proclaiming his own merits.

An engineer may practice his profession in either one of two ways, *viz.*, (1) as an employee of a corporation, such as a railroad, a public utility, an industry, a city or other public body, which has sufficient engineering work to do to warrant maintaining its own regularly organized engineering staff; or (2) as an engineer, or the employee

of an engineer, engaged in open private practice, commonly called a *consulting engineer*, who undertakes to perform engineering services for anyone who may retain him.

In the first type of work, the engineer receives regular salary and devotes all of his time to one employee, working cooperatively with the other engineers on the staff. In the second group, an engineer in private practice may charge for his services a per diem (per day) rate, or he may charge a retainer fee plus a per diem rate, or he may charge on the basis of the cost of the work, say 5 per cent of the cost, where both design and inspection of work are required of him.

In either case, the professional service rendered consists of advice concerning plans, procedures, or the status of existing works. When an engineer becomes an executive, as so frequently happens, his function is to direct the operations of others, either near or remote from the technical activities.

In the early years of his practical life, an engineer may expect to act as an assistant to more experienced engineers, performing subprofessional duties and working under direction. The work that he will do in this capacity will include making surveys and other measurements, drafting, computing, testing, clerical work, and inspection. So much of the ultimate practice of engineering is the result of experience that such assistant positions afford a natural vestibule through which to enter the more definitely professional phases of engineering. This period corresponds to an interneship for a physician, but fortunately in engineering there are elementary duties that may be done satisfactorily by the beginner while he learns the more complicated features of the work, and, hence, the young engineer

has the ability to earn a salary from even his first employment.

Instrumentalities of Engineering. The instrumentalities which an engineer must utilize are represented diagrammatically in Fig. 3 and may be termed the four M's of the engineer. The first two are matters of exact science, while the last two are matters of judgment and experience.

Method involves largely the science of engineering, such as calculating the magnitude of forces, power

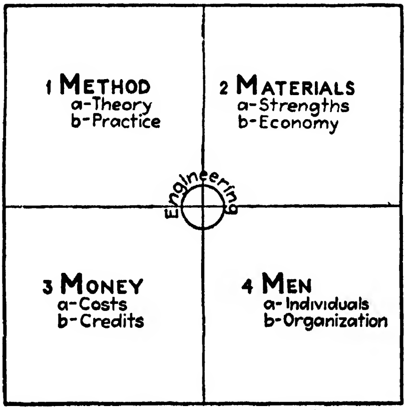


FIG. 3.—The four M's of engineering. Capability in these four realms will bring professional success.

yield, pressures, water yield of a stream, and the capacities of machines.

Materials includes a knowledge not only of primary materials, such as iron, steel, copper, aluminum, stone, and timber, but of their derivatives, such as concrete, bronze, alloy steel, brass, duralumin, carborundum, carboloy, permalloy, and other alloys. The properties of these materials, such as strength, hardness, flexibility, elasticity, and durability, must be known quantitatively, hence the study of materials is an important factor.

Money is a fundamental of all engineering work, for the first question is always whether to undertake a project or not, and that question will usually depend on costs. Successful manufacture, successful construction, or successful operation all depend upon unit cost. As one prominent engineer put it, "Whatever may be the numerator of an engineer's fraction, dollars will always be the denominator." How much accomplishment per dollar is the controlling factor. An apt and much-quoted definition of an engineer is "one who can do well with one dollar what any blunderer can do after a fashion with two."

Money in large sums is an indispensable element in an engineer's work because of the magnitude of the projects with which he deals. For example, a state highway program, a municipal sewerage system, a railway improvement, a power plant, a factory, or a large bridge may cost several million dollars, sums that cannot be included in a regular annual budget and expended from regular income. Such projects require special measures of financing, such as bond issues to amortize the debt or else some scheme of anticipating the expenditure through reserve funds. Also engineering touches corporations, which render the necessary economic service of assembling small investments into large pools of productive capital beyond the range of individual wealth.

Men constitute the fourth instrumentality that an engineer must be able to use intelligently if he is to succeed in his profession. How to handle men is as important, even though less capable of analysis, as how to handle method, materials, or money. Not only may the engineer have to direct large forces of workmen who have to be organized, coordinated, housed, fed, and kept in good health, but he must be able to work harmoniously

with colleagues and superiors in an organization. He must recognize that candor and straightforward dealing with men will obtain and hold their loyalty and a sympathetic understanding of their personal problems will win their affection. Just dealing should be honest and correct dealing; no amount of cajolery will counteract the effects of evasion, shifting responsibility, or discrimination. The motives which actuate men must be kept in mind by the engineer.

The engineer will frequently have to deal with organized labor, *i.e.*, with labor unions, and he should be acquainted with their methods of procedure. There are skilled trade unions, such as printers, carpenters, masons, and electricians, distinguished from the industrial unions, such as miners, car builders, railway trainmen, and other railway brotherhoods. These are all organized with a view to collective bargaining with the employer. The local unions are usually federated into larger organizations, such as the United Mine Workers of America and the American Federation of Labor. Labor contracts as to hours, wages, etc., are commonly made between the employer and the union, where the former is a corporation, or between an association of employers and a union or federation of unions. The complexity of labor organization requires careful consideration by the engineer who engages in contracting or other work involving large numbers of workmen in various crafts.

The Branches of Engineering. The principal branches of engineering as they now exist are shown diagrammatically in Fig. 4, which represents the roads to the various fields of engineering together with the more important interests in each field.

Chemical engineering covers manufactures of organic industries, such as rayon and leather substitutes, drugs,

and cellulose explosives; heavy chemicals; paper; soap; foods, such as sugar, cereals, fruit preservation, and artificial fats; fuel industries, gas plants, petroleum and tar products; paints, varnishes; glass industries; and fertilizer. The chemical engineer may plan the process involved in these and in the metal industries; he may operate the plant, or he may work in the laboratory controlling the operations and testing the products.

Civil engineering includes principally railroad, highway, hydraulic, sanitary, city or municipal, structural engineering, and contracting. In railroad work, the civil engineer may be engaged in the surveys and location of new lines or in improving old ones, as inspector or resident engineer on work during construction, in laying out new yards and terminals, in aligning existing track, correcting curves and grade, and designing railroad structures of various sorts. In highway work, he may make surveys for new locations, make traffic surveys, direct city or rural paving operations, make designs for highway bridges, or superintend maintenance and repairs to highways and streets.

In *hydraulic* work the civil engineer may make hydrographic surveys and stream measurements to ascertain the flow of streams, design and construct levees and other river-training works, design and construct drainage systems; design, construct, and operate irrigation projects, ship canals, and hydraulic power developments. In *sanitary* engineering, he may design, construct, and operate city water systems and sewerage works, plan garbage disposal, or inspect water and sewerage works for public departments of health. *Structural* work includes the design and construction of bridges, buildings, and other structures of timber, masonry, reinforced concrete, and steel which may be done for the public or

ENGINEERING EDUCATION

The gateway to the engineering profession is a college of engineering, which should contribute to your education in three respects:

A- INTELLECTUAL POWER
1 - The ability to observe and think correctly
2 - Knowledge of facts and of men
3 - Facility in expression, both oral and written

B- ATTITUDES (Emotional)
1 - Honesty in dealings and in thinking
2 - Friendship and loyalty to fellow workers
3 - Good citizenship and ethics

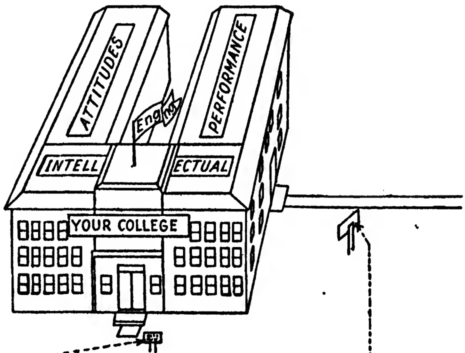
C- PERFORMANCE (Volitional)
1 - Standards
2 - Initiative and decision
3 - Punctuality and persistance

College brings to you the following agencies from which to benefit:

A- PERSONS
1 - Teachers
2 - Fellow students

B- BOOKS
1 - Bound volumes
2 - Periodicals

C- EQUIPMENT
1 - Laboratory
2 - Inspection of practical engineering work



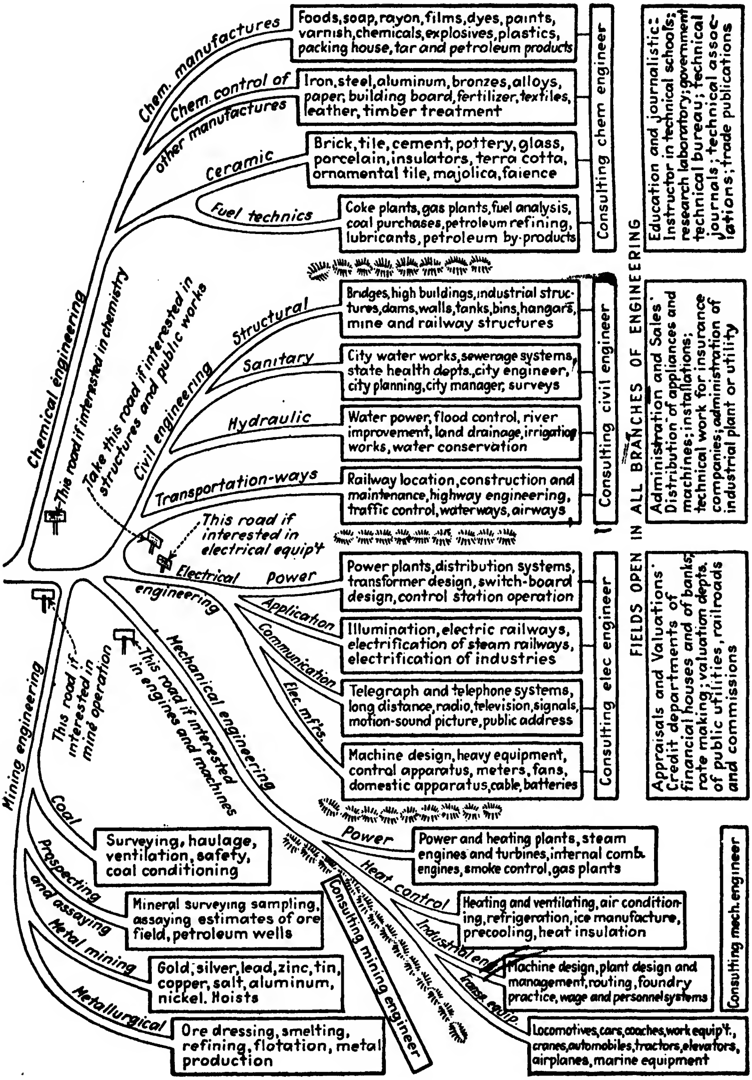
Who should enter here? Boys who make good records in mathematics and physics while in high school and who are interested in structures and machines will probably be successful in engineering

Similar mental abilities required for all branches; opportunities about equal in all branches, choice should be determined by inclinations

ROAD MAP OF ENGINEERING

Diagrammatic sketch showing main routes, the fields to which they lead, and direction signs for making a choice

FIG. 4.—The road map of engineering. Entering gateway, established there are many fields of engineering endeavor, relatively few main roads, branches and specializations develop later in engineering practice.



roads; direction markers, and fields of professional operations. Although indicated by the college curricula, lead out from college. The minor

for private corporations. Deep and difficult foundations are frequently designed by structural engineers who have specialized in that line.

In contracting, the engineer's work consists in making estimates on the work for the purpose of bidding, in selecting and purchasing building materials, in organizing the force of men, materials, funds, and equipment in a manner to finish the work most economically.

Electrical engineering covers electrical manufactures, electric power generation (usually with a public utility), communication, illumination, and power application.

In *electric manufactures*, the engineer designs special generators and motors, transformers, and electrical appliances and tests the same. In *power generation*, he may design the power-equipment installation, the transformer setup, the switchboards and transmission lines; he may also superintend the construction and the operation of the same. In *communication* work, he may design and erect telephone switchboards at exchanges, have charge of toll lines, and act as expert on telephone interference. He may also serve in the signal department of a railroad, or in the manufacture and installation of radio, television, and sound-movie equipment in theaters.

In *illumination* work, the engineer gives expert advice to industrial plants and to architects with regard to the lighting of large buildings, to airports on flood lighting, and to cities on street lighting. Electrical *application* work includes the design and construction of railway electrification projects and electric traction generally, the installation of electric elevator and conveyor systems, and the application of electric power to running manufacturing machinery.

Mechanical engineering covers machine design, aeronautical and automotive engines and equipment, refriger-

ation, heating and ventilating, power-plant design, and operation, manufacturing, and the mechanical equipment of railroads.

In *machine design* the mechanical engineer may prepare plans for steam engines, turbines, rolling-mill machinery, presses, gears, special process, and automatic machines. Opportunities are open for original invention in these lines.

Aeronautical and *automotive* engineering largely clusters about the efficient operation of the internal-combustion engine and the action of air on the bodies. In *refrigeration* work, the engineer designs systems for the manufacture of ice, for precooling, storage, and transportation of fruit and other perishable foods, for the packing of meat, and for smaller refrigeration units. *Heating and ventilating* plans are prepared by the mechanical engineer most frequently in connection with the architect who plans a building. The design, construction, and operation of large *power plants*, their boilers, turbines, coal- and ash-handling equipment, feed-water purifiers, their condensers and economizers offer large opportunities for the mechanical engineer. Locomotive and *railway-equipment* manufacturers require mechanical engineers for designing such equipment, while railroads employ them to supervise maintenance in the motive power and equipment departments.

Mining engineering includes the location, design, and operation of metal mines, coal mines, and petroleum wells and also smelting and marketing operations.

The location of mines at first covers prospecting and underground surveying, while the design of mine bracing and workings is a specialized art. Designing mine railways, usually electric, together with head frames and

other facilities for handling and transporting the ore, constitutes the chief engineering problem.

The driving of oil wells and the operation of pumping systems are a specialized aspect of mining engineering rather widely separated from metal- and coal-mining operations.

Metallurgy, which literally means *metalworking*, has developed into a basic science in the control of the properties of metals and their alloys. It includes physical metallurgy, chemical metallurgy, electrometallurgy, and metallography. In recent years, the art of welding and the science of controlling the properties of steel by heat-treatment are important applications.

Specialties in Engineering. Numerous highly developed branches of the major divisions of engineering have taken on specialized names, organized separate professional societies, and otherwise attained distinctive identities. Also specialties in physics, chemistry, and geology have developed into professions allied to engineering. However, the major divisions persist because they involve distinctive fundamental principles, and therefore, preparation for a major division will serve as basic training for a specialty. Thus from civil engineering, specialized branches include hydraulic, sanitary, municipal, city planning, railway, highway, structural, airport, and others; from mechanical engineering, aeronautic, automotive, heating and ventilating, industrial, marine, power plant, and others; from electrical engineering, illumination, radio, telephone, signal, and others; from chemical engineering, ceramics, explosives, sugar refining, petroleum, plastics, and others.

Industrial engineering comprises the layout of factories and the management of operations, wage systems, inspection methods, purchasing, and efficiency methods.

Marine engineering treats of the design of the power plant, the transmission system, and the control devices of ships.

Agricultural engineering embraces the elements of surveying and the structures and machines applicable to agricultural operations.

Architectural engineering is a hybrid of structural engineering and architecture aimed at the structural and equipment design of large buildings.

Ceramic engineering covers the kilns and other devices used in the manufacture of brick, tile, glass, cement, and other products derived from clays, shales, sand, and rocks. Ceramics in nonmetals corresponds to metallurgy in metals.

The term engineering is also sometimes applied improperly to a great number of other specialized technologies limited to some phase of industry or to some trade practice, most of which do not require scientific preparation, the specialization being acquired from practical work.

Development of the Engineering Profession. In ancient times, among the Greeks and Romans, the term *architect,* derived from the Greek word *architecton* (*archi* + *tecton*) meaning chief builder, was applied to the one who planned buildings and all public works, such as canals, monuments, waterworks, or drains. The ancient word *architecture,* therefore, comprised not only what is now included in that term but what is comprised in engineering (civil) as well, and the term continued to have this comprehensive meaning until about the eighteenth century.

In the later Roman army, a group of men of special training, called *ingeniarii,* were assigned to build fortifications, roads, and other such work, and until about the

sixteenth century, the term *engineering* meant principally military engineering. The Latin word *ingeniator* was applied to a man who made ingenious devices for either military or civil purposes.

With the growth of public works, the improvements of iron and other building materials, and the development of the art of planning such works, men engaged in designing and building public works other than military called themselves *civil* or *civilian* engineers, as distinguished from military engineers. Even as late as 1650, when Thomas Rudd was appointed "Chief Engineer" to the king in England, his duties were largely military. Men who built industrial structures were commonly called "millwrights." About 1771, John Smeaton, a designer of bridges and other structures, of drainage works, pumps, steam engines, and other machines which were beginning to be numerous at that time, was the first to advertise himself as a "civil engineer," and his report on the Eddystone lighthouse contained the phrase "my profession of a civil engineer." He regularly signed his name "John Smeaton, Civil Engineer," and he may properly be remembered as the first civil engineer. In 1793 occurred the first meeting of the Society of Civil Engineers of London. The Institution of Civil Engineers was founded in 1818 and the American Society of Civil Engineers in 1852.

With the development of the steam engine and other machinery, mechanical engineering for those primarily interested therein became separated as a distinct profession, leaving in the original stem of civil engineering those projects of a stationary or static character. The Institution of Mechanical Engineers in England was founded in 1847 with George Stephenson, the locomotive

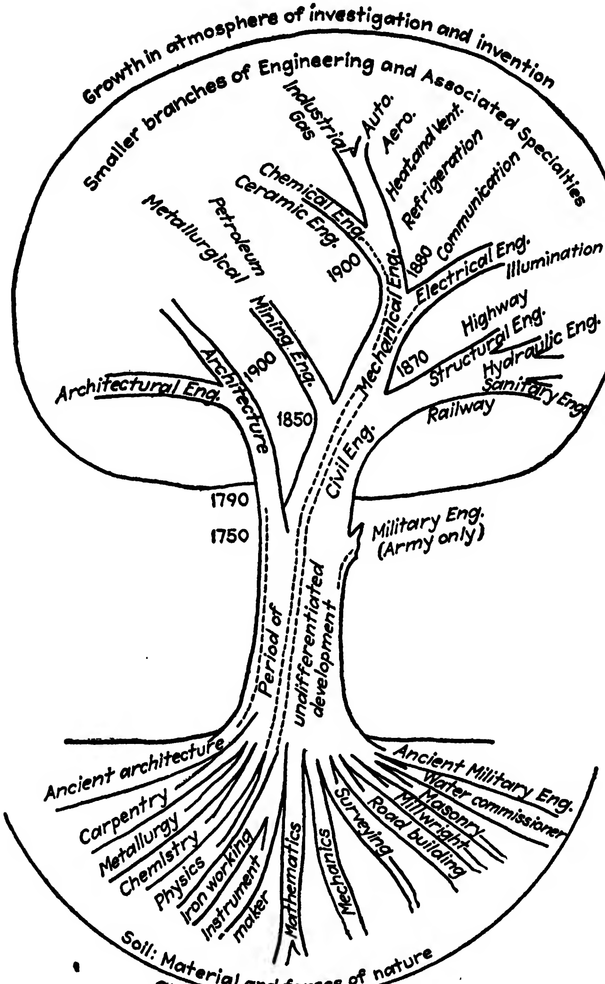


FIG. 5.—The family tree of the engineering profession. This family tree is about 150 years old, although the seed had lain dormant for centuries. The present state of the engineering profession is the result of growth and branching, somewhat like a tree. Several branches, partially recognized as specialties, are now in the process of formation.

builder, as its first president, and the American Society of Mechanical Engineers in 1880.

At about the same time, mining engineering branched off to include the operations involved in extracting useful minerals, testing and valuing the ores, and designing the required works both above and underground. The Institution of Mining Engineers was founded about the middle of the century and the American Institute of Mining and Metallurgical Engineers in 1871.

In a similar manner, when electrical machines and other devices began to have wide application, electrical engineering branched as a separate profession. The Institution of Electrical Engineers was founded in 1883 and the American Institute of Electrical Engineers in 1884.

With the growth of chemical manufactures and chemical control of mechanical manufactures, still another branching has occurred known as *chemical engineering.* The American Institute of Chemical Engineers was founded in 1908.

Figure 5 represents graphically this record of professional development.

Kinds of Engineering Work. Whatever branch of engineering one may enter, one's work will be likely to fall under some group name that may be designated as a particular kind of engineering. Thus he may be called a *research engineer* if his work consists of investigations intended to find new principles and methods, regardless of whether he may be in chemical, civil, electrical, or mechanical engineering. In a similar way, if his work involves calculations and designing structures or machines, he may be called a *designing engineer;* or if concerned with erection of structures, machines, or plants, a *construction engineer,* or perhaps *superintendent of con-*

struction; or if his work concerns maintenance and operation, he may be called a *maintenance engineer* or an *operating engineer.* The terms *sales engineer* and *application engineer* are of a similar sort relating to selling and installation of equipment. These terms, however, relate

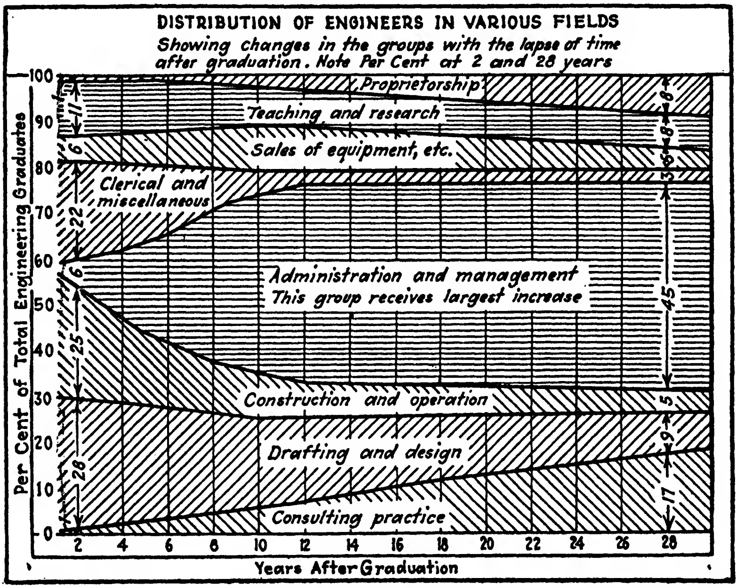


FIG. 6.—Distribution of engineers in different kinds of work. About three-fourths of all engineers ultimately occupy executive or managerial positions.

to the kind of work done rather than indicate professional groupings. Engineers to a great extent gradually move up into administration and management or other positions of executive responsibility, as shown in Fig. 6, although many prefer to remain in the strictly technical phases of the profession.

Relation between Student Scholastic Record and Commercial Success. Investigations show definitely

that there is a direct relationship between success in college studies and success in professional or business life. High grades in classes in most cases mean high salaries in the industrial world. In *Harper's Magazine* for May, 1925, Walter S. Gifford, President of the American Telephone and Telegraph Company, gave a summary of studies of the correlation between college success and success with that company. The study involved 4,125 persons, graduates of 104 different colleges. The top 10

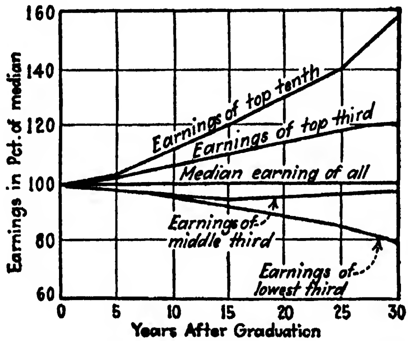


FIG. 7.—Relation between scholarship record in college and earnings in practice. High scholastic attainment increases the chance of professional success.

per cent in scholarship earned on the average 20 per cent more than the median salary for all college men at the end of 15 years and 55 per cent more than the median at the end of 30 years out of college; while the lowest third in scholarship earned 10 to 20 per cent less than the median between these corresponding years.

Dr. W. T. Foster, President of Reed College, after a study of the records of West Point, a school of forestry, an engineering school, and some other colleges, concluded that, "Indeed, it is likely that the first quarter in scholarship of any school or college will give to the world as many distinguished men as the other three quarters."

A study by D. S. Bridgman of the American Telephone and Telegraph Company[1] shows that there is a direct relationship between scholarship record and professional success. The results of Mr. Bridgman's studies are redrawn in Fig. 7. They show that the earnings of those in the top tenth of the class are considerably higher than the average and that this difference increases through the years, amounting to about 55 per cent more at the end of 30 years. In a similar manner, the earnings of the upper third are higher than the general average, while the middle third and lower third in scholarship have earnings below the average. Those of superior scholarship not only earn more salary on the average but usually perform more interesting and more important work.

A comparison of the average earnings of members of Eta Kappa Nu, the honorary electrical engineering fraternity whose members are restricted to students of high scholarship, with the earnings of electrical engineers generally showed the former to be considerably higher.[2] Also a study made by the author at one engineering school of the earnings of members of Tau Beta Pi, whose membership is based chiefly on high scholarship, showed the earnings of members much above the average of their respective classes.

A study covering several industries[3] indicated that a student in the upper third stood about twice as good a chance of being successful as a student in the lower third, and that a student in the top tenth stood three times as good a chance at success as the average.

Value of Campus Activities. A student is usually faced with the question, Which will mean the most to

[1] *Personnel Jour.*, vol. 9, pp. 1–19, June, 1930.

[2] *Soc. Promotion Eng. Education Rept.*, 1929, p. 377.

[3] *Jour. Soc. Promotion Eng. Education*, January, 1930.

him: superior scholarship or participation in campus activities? The results of Mr. Bridgman's studies on this point also throw some light on this question. Mediocre or little achievement in campus activities was found to have little, if any, effect on success. Campus achievement of the nature of leadership in debating and editorial and managerial work seems to have considerable influence on professional success, especially for the students of the middle and lower thirds in scholarship. Achievement in social life, in athletics, in dramatics, and in music appears to have very little bearing on professional success; although, of course, these might be of value to the individual in adding to his enjoyment of life.

Factors That Affect Salaries. In addition to technical skill and general capability, there are two factors which affect the size of salary that an engineer may receive, and these factors should be understood by every young man going into the profession. Those factors are (1) tenure or permanency of employment and (2) opportunites for professional development.

When an engineer engages to work on a projected enterprise on terms such that his employment is dependent entirely on the success of that enterprise, there is a hazard to his professional career involved that requires a higher rate of compensation than would be the case if he were working for an established concern with many activities under way which would be little affected by the success or failure of any single enterprise. For example, a projected railroad or an irrigation development in an undeveloped region might offer a young engineer recently out of college the high-sounding title of "chief engineer" at a relatively large salary, when the best that he could do with a well-established railroad, in a city engineer's office, or with a well-established firm of

consulting engineers would be a humble assistant at a very modest salary. In the first instance, there is hazard of future employment and the possibility of being connected with an enterprise that may prove to be professionally discreditable and with no opportunity to learn greater professional knowledge from engineers of greater experience than himself. These disadvantages must be compensated for by increased rank and salary rates.

The compensations of the position in the established organization, in addition to salary, are the opportunities to acquire knowledge of how engineering work of that sort has been carried on in the past, direct help and advice from superiors, and also the greater probability of continuous employment.

A former student of the writer's was attracted to a position as chief engineer of a locating party for a proposed railroad in a newly developed foreign state. On a certain Saturday night when the group received their pay, they were surprised to be told that the work was to be abandoned at once, and they were left to find their way several hundred miles back to a seaport from which to return home (at their own expense).

Opportunities, therefore, are to be measured not by immediate salary alone but by the relation of the position to one's entire professional life of perhaps 50 years.

Beginning Salaries. Beginning salaries for graduates in engineering vary somewhat and usually reflect the other compensations of employment to some degree. That is, in a position with a large well-organized company where the beginner will require several weeks to learn enough about the work and the organization to enable him to do more than routine under immediate supervision, the pay will be less than on a force so elemen-

tary in its organization that he may at once begin to do work at a regular rate. However, in the more elementary kind of work, he will learn less that will ultimately contribute to his professional success; hence the actual compensation cannot be gaged entirely by the nominal monthly pay check.

A study of beginning salaries of electrical engineering students[1] indicates a fairly steady increase in beginning salaries from about $1,200 per year in 1920 to $1,600 per year in 1930. Since 1930, beginning salaries have been considerably increased.

A study made in 1930 by the Federal Office of Education of the graduates of 35 engineering schools indicated that beginning salaries of engineering graduates varied from about $120 to $200 per month, about 15 per cent receiving less than the former figure and about 1 per cent receiving more than the latter; about half received salaries between $125 and $150 per month.

Earnings of Civil Engineers. A committee of the American Society of Civil Engineers, in 1916, made an extensive study of earnings of civil engineers[2] covering maximum, minimum, and median earnings, the earnings in different groups of employment, and also a geographical distribution as to various parts of the United States.

Graduates of technical schools were found to be earning about one-fourth to one-third more per year than those whose education fell short of graduation.

The rate of compensation from highest to lowest placed the groups in the following order: contractors, consulting engineers, private companies, railroads, technical schools, municipalities, national governments, states, and counties.

[1] *Jour. Soc. Promotion Eng. Education*, vol. 20, p. 849, May, 1930.
[2] *Trans. Am. Soc. Civil Eng.*, vol. 81, p. 1207, 1917.

Compensation ranged highest in the Middle Atlantic States, and successively lower in the Central States, New England, Western States, and Southern States.

The average salaries of civil engineers naturally increase almost directly with the number of years' experience up to about 30 years, after which time the average declines somewhat. The maximum increases up to about 20 years' experience, remains fairly uniform for about 20 years, and then diminishes. The minimum salary remains at a fairly uniform figure, equaling approximately the wages of a skilled workman.

At the time of this investigation, the maximum yearly compensation ranged from $12,000 for 5 years' experience up to $100,000 and $150,000 per year for a few of the most capable and experienced men. The figures of average earnings of that time are of relative significance only at present because of the variation in the purchasing value of the dollar. Figure 8 shows the results of this study and also the results modified for the 1930 price index.

Earnings of Electrical Engineers. Several studies of the earnings of electrical engineering graduates have been made, such as that by the Eta Kappa Nu electrical engineering honorary fraternity[1] and by Prof. R. G. Kloeffler.[2] The former covers the experience of the more capable of electrical engineering graduates and the latter the graduates of one Middle Western institution (see Fig. 8).

The latter study has already been mentioned for information on beginning salaries; it covers the classes of 1916 to 1925. The average electrical graduate of that institution advanced in that war period about $200 to $300 per year for each year following graduation.

[1] *Jour. Soc. Promotion Eng. Education*, vol. 22, p. 723, May, 1932.

[2] *Jour. Soc. Promotion Eng. Education*, vol. 20, p. 847, May, 1930.

The rate of advance of the upper 25 per cent of these averaged from about $300 to $400 per year increase in

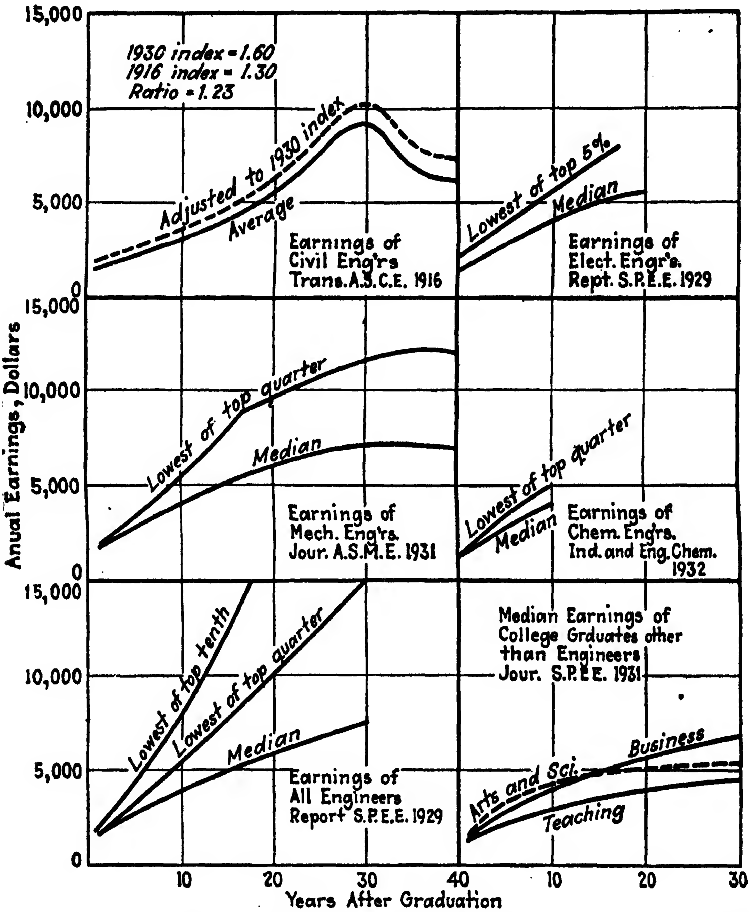


FIG. 8.—Earnings of engineers at various years following graduation. Average earnings of college graduates in other vocations are also shown.

salary for each year following graduation, and the lowest 25 per cent averaged about $100 to $150 per year increase for each year following graduation.

The beginning salary advanced from about $800 per year in 1916 to $1,600 per year in 1929.

The results of the Eta Kappa Nu studies showed that the earnings of electrical engineering graduates average essentially the same as those of all engineering graduates. They showed earnings largest in Northeastern States, next highest in Central States, and lowest in Southern and Western States. As to kind of work, the salaries ranged from high to low in the following order: communication, miscellaneous manufacture, electrical manufactures in large companies, electrical manufactures in small concerns, and electric light and power.

Earnings of Mechanical Engineers. In 1930 the American Society of Mechanical Engineers made a comprehensive investigation of the earnings of mechanical engineers.[1] These studies indicate an initial salary about the same as in other branches, $1,200 to $2,000 per year, followed by about a 15- to 20-year period of rapid increase, a 15- to 20-year period of slow increase, and then a decline in the median salary. The average salary shows an increase of about $250 per year for the first 20 years, followed by a somewhat lower rate of increase and then a decline (see Fig. 8).

These investigations of mechanical engineers showed that graduate engineers earn about one-fifth to one-third more than nongraduate engineers, and that engineers with postgraduate training earned slightly more than those with the B.S. degree only.

> Technically trained men from recognized engineering colleges command median earnings $500 over men with inferior training from the time they are twenty-five until they are thirty-five years old. Above that age they rapidly forge ahead until at forty-five they are $1,000 [per year] ahead of the men without technical training.

[1] *Mech. Eng.*, September, November, December, 1931.

The studies further showed earnings highest in Middle Western States, next in order, the Middle Atlantic States, the New England, the Southern, and the Western.

As to kinds of work, earnings were in the following order: general management, consulting, buying and selling, technical operating, designing, and education.

Earnings in different types of industries ranged as follows from high to low: nonmetal manufactures, chemical manufactures, machinery manufactures, power machinery manufactures, public utilities, and railroads. The conclusion was reached by the committee that the difference in earning among the different industries is not great.

The earnings of those who combine with their technical ability the capacity to manage an independent business or to handle men or affairs are so great as to indicate the importance of striving to develop this capacity.

Earnings of Chemical Engineers. Chemical engineering, being the youngest of the engineering professions, has less of a record from which to draw conclusions as to earnings. Observations indicate that their earnings correspond generally to those of men in the other branches of engineering. A. H. White, Professor of Chemical Engineering at the University of Michigan, collected some data[1] from which the following facts are extracted:

General engineering and sales work yield higher earnings than research, technical analysis, laboratory, plant development, or plant operation.

Graduate study leads to laboratory and technical work without a commensurate increase in earnings. In plant work, however, those with one year graduate study earn appreciably more than those with only the B.S. degree.

[1] *Ind. Eng. Chem.*, February, 1932.

Earnings begin at about $1,800 per year and increase at successive years after graduation as shown in Fig. 8.

Of the graduates in classes between 1920 and 1930, 29.5 per cent were engaged in teaching, graduate study, or research, and the remainder in the following industries with the percentage indicated: petroleum, 12.3; organic chemicals, 9.0; heavy chemicals, 5.0; rubber, 5.0; iron and steel, 4.9; gas and coke, 4.3; paint and varnish, 4.2; pulp and paper, 4.0; nonferrous metals, 2.5; soap, 1.8; automobiles, 1.5; chemical equipment, 1.5; power plants, 1.2; food, 1.2; rayon, 1.0; ceramics, 0.9; cement and lime, 0.9; textiles, 0.4; fertilizers, 0.3; leather, 0.2; and miscellaneous, 8.3.

Earnings of All Engineers. In 1924, an extensive investigation was made by the Society for the Promotion of Engineering Education into the earnings of all engineers in the United States and Canada. The median salary began at about $1,500 the first year after graduation and increased rather steadily about $200 per year up to $7,500 at the end of 30 years' graduation. The lower salaries of the top 10 per cent began at $1,800 and increased to $7,500 at the end of 10 years, to $17,500 at the end of 20 years, and to $30,000 at the end of 30 years. The upper boundary of the lowest 25 per cent began at about $1,200 and increased to about $4,500 at the end of 30 years (Fig. 8).

These earnings are about equal to the earnings in other professions. For example, the committee on the Costs of Medical Care,[1] from a study of incomes of 13,000 physicians, found that only about 1 per cent have a net income as great as $15,000, that only about 5 per cent earn as much as $8,000 net, that the majority earn $3,000

[1] *Report*, Committee on Costs of Medical Care, 1932, University of Chicago Press.

to $6,000 net, and that 10 per cent earn less than $2,500 per year.

The same report shows that most dentists in private practice earn from $2,000 to $6,000 net, only about 1 per cent earn over $7,000, and 10 per cent earn less than $2,000 per year.

While the results of a general study of lawyers are not available, an investigation among the alumni of one law college with a long record and many graduates indicates that the earnings of law graduates are similar to the earnings in other professions, although somewhat lower for the first 8 years and somewhat higher after the first decade.

Earnings of graduates of land-grant colleges, other than engineering, are shown in Fig. 8.

Data collected by the Bureau of Labor Statistics[1] and by various other agencies approximately confirm the foregoing average incomes under peacetime conditions (1934). Postwar salaries will probably run according to a similar pattern but will rise in proportion to general price ratios.

Engineering a Preparation for Industry. L. W. W. Morrow states:[2]

> Data on 54,000 officers of some 500 typical industries showed that the average college man is seven times more likely to become an official than a noncollege man, and that the engineering graduate is thirty times more likely to be an official than a graduate of a non-engineering college. . . . He has twelve times the chance to become president, five times the chance to be treasurer, thirty times the chance to hold a position in production, 174 times the chance in engineering, and twenty-four times the chance in sales.

Engineering is intimately related to industrial development as is evidenced by the fact that the numbers of

[1] *Dept. Labor Bull.* 682.

[2] *Elec. Eng.*, November, 1938.

engineers have increased in proportion to the growth of industry. While the numbers of lawyers, physicians, and clergymen per million population have either remained stationary or diminished, the numbers of engineers per million population have greatly increased, keeping pace with industrial growth.

Licensing Professional Engineers. Practically all states now have registration laws for licensing professional engineers designed to secure competence on the part of those who profess to serve the public. A profession is assumed to involve specialized arts, sciences, and skills beyond common knowledge which are vital to public safety and welfare; hence, the competence of practitioners is examined by a qualified board and certified by licensure to the public. The state law usually provides a penalty including fine and imprisonment for practicing without a license. Although requirements vary in different states, they commonly include academic preparation equivalent to the 4-year college course plus a term of about 7 years of significant practical experience. These qualifications must be established by such examination and inquiry as the state board may deem appropriate. A young engineer may work as an assistant to a licensed engineer until he acquires the necessary experience for his own license. Licensure is a strong influence toward the unification of the profession, since it undertakes to designate those who are qualified to serve society competently either privately or through corporate and governmental bodies. The diversity of matters falling within the province of engineering makes difficult a legal definition of engineering sufficiently sharp for administration; hence obstacles have arisen that seem to make probable some changes in procedures. An engineer should obtain a license as early as he can qualify.

In recent years, there has been a tendency for technicians and others in the routine technologies connected with engineering to form unions affiliated with the national labor organizations. In this circumstance, the professional phases of engineering emerge from the technical crafts. Indeed, the most recent of the state licensing laws, devised to remove obscurity in legal definition, ascribes professional engineering to the planning and designing functions. A young engineer should avoid any organizational attachment that will restrict his freedom to work and impair his opportunities for professional progress, although under present laws he may be required to have membership in a group bargaining agency.

Professional Ethics of Engineering. The aim to serve society faithfully is implicit in a profession. Accordingly, groups of engineers have adopted codes of ethics which set forth in general terms their responsibility to the public together with certain customs of fair practice designed to uphold the dignity of the profession. The engineering profession has a notable record for fidelity which the members cherish and safeguard. The following code of professional ethics is an abridgment of the "Canons of Ethics" proposed by the Engineers' Council for Professional Development:

CODE OF ETHICS FOR ENGINEERS

In order that society may be well served, the dignity of the profession preserved, and the equities of practice maintained, it is the duty of every engineer to:

1. Carry on his profession with a fidelity worthy of its high responsibility as an essential service to mankind and with the scrupulous honesty and justice which characterize the engineering tradition.

2. Advance his profession by contributing from his observations to the common store of technical knowledge in society proceedings

and other educational agencies, and to enlighten public understanding of the significance of engineering works by disseminating information wherein he may have knowledge.

3. Protect the good name of the profession and the reputation of other engineers against unjust blame, but not to withhold exposure of dishonesty when found.

4. Compete fairly and forthrightly, eschewing all artful solicitation, boastful advertising, or the improper use of an advantagous connection, such as a salaried position, in procuring business.

5. Obtain for himself and to pay his assistants a compensation appropriate to the services rendered, and to give to other engineers due credit for their collaboration.

6. Be diligent, confidential, and loyal in promoting the interests of his employer or client within the limits of truth and honor.

7. See to it that his financial relationships to all parties involved in any particular engagement are known and that his own professional judgments are unbiased by any pecuniary interest not apparent.

8. Avoid hazards to employees and to the public so far as possible and to call attention to any hazards whose removal is impracticable.

9. State only his convictions in giving professional testimony before any tribunal and to refrain from expressing opinions wherein he lacks information.

10. Avoid lending his professional support knowingly to a device or enterprise that is fraudulent or useless for the benefit of mankind.

CHAPTER III

OBJECTIVES OF ENGINEERING EDUCATION

Education. Education means cultivating, developing, and training the native faculties in their function and coordination. The educational process has four aspects intellectually: (1) acquiring and assimilating certain knowledge that has been accumulated by the race to serve as a background for thought; (2) the development of certain mental skills of observation and inquiry in seeking new knowledge; (3) a discipline in orderly and effective modes of thinking, together with criteria for discriminating and testing the conclusions drawn; and (4) securing such command of language as will give facility and precision in expression.

College, with its teachers, laboratories, and libraries, constitutes merely an environment favorable to such development, where the student's capabilities will be cultivated to grow into their most perfect attainment instead of being dwarfed or atrophied through disuse in unstimulating surroundings. The student's possibilities of education are limited by the inherited powers, just as in physical development his final stature is limited by native physique regardless of any efforts toward physical training.

The student is not a vessel, therefore, to be filled with knowledge; he is rather a growing and expanding organism to be guided and trained in his growth. He has physical, mental, and moral fibers that need to be exercised, corrected, coordinated, and strengthened. He has

wits to be sharpened, certain timidities to be eliminated, and social qualities to be adjusted through contacts with associates. His powers of observation must be made more discriminating and refined by comparing with the observations of more experienced men, and his faculty for inference and judgment made more certain by checking against known conditions and confirmed conclusions. In a like manner, the qualities of the will, such as persistence, industry, honesty, and punctuality, are cultivated by a conscious effort in that direction. The student becomes educated through the effective development of his faculties to the end that each is brought to a high level and that all faculties are coordinated to constitute a harmonious whole.

Kinds of Mental Habits. Somewhat modified from the summary by A. S. Edwards, Professor of Psychology at the University of Georgia, the following classification of desirable mental habits is helpful as an outline,[1] since education consists largely in forming good mental habits.

A. Intellectual habits.

1. Habit of observing carefully, accurately, and completely.
2. Habit of clear and accurate association and recall.
3. Habit of concentration or undivided attention.
4. Habit of open-mindedness, ready to receive new information and to change an opinion if warranted.
5. Habit of making clear, accurate, and logical judgments based on information at hand.
6. Habit of thinking over and testing old ideas and conclusions from new points of view.
7. Habit of inquiry into cause and effect relationships.
8. Habit of questioning the adequacy of evidence and the correctness of accepted dogmas.
9. Habit of coming to definite, although tentative, decisions and conclusions on the basis of information available.
10. Habit of careful diction and discourse.

[1] "Fundamental Principles of Learning and Study," p. 22.

B. Emotional habits. (Feelings and attitude.)

1. Habit of permanent interests, in science, literature, art, government, etc., rather than a flitting from one to another.
2. Habit of a desire for truth uninfluenced by personal desires.
3. Habit of being just, fair, and honest toward others.
4. Habit of courtesy.
5. Habit of self-confidence with a proper tolerance for the views of others.
6. Habit of a reverent appreciation of one's relation to the universe.

C. Motor (volitional) habits. (Performance.)

1. Habit of quick action when the appropriate action has been determined.
2. Habit of orderly and neat arrangement of calculations and other written work.
3. Habit of skill or technique in writing, drawing, handling instruments, etc.
4. Habit of punctuality.
5. Habit of persistence.
6. Habit of planning one's affairs.

Plan of an Engineering Education. The general objective of an engineering education is to prepare men for the practice of the profession and for making contributions to the advancement of the science of engineering. Inasmuch as this preparation involves both capability and qualities of character, engineering education has three aspects: power to think (intellect), attitudes (emotions), and performance (volition).

Intellectually, engineering education involves a *mode of thinking*, which is described as being quantitative, concrete, objective, and definite, striving toward exactness, in contrast to qualitative, abstract, and subjective thinking, aimed at general impressions and conjecture. It is essentially mathematical in character, even though the formal mathematics required may be rather elemen-

tary. For example, any well-informed man knows that the burning of coal in a boiler generates steam which, passing into the engine, expands and thereby causes the piston to move and the wheels to rotate. The engineer, in contrast, must know *how many* pounds of coal each yielding a *known number* of heat units are required to generate a *required number* of pounds of steam at the *pressure intensity* for which the boiler pipes and engine were designed, to yield a *desired number* of horsepower or kilowatt units of usable power. His thinking must not only include the *technical quantities* but must also include the *cost quantities* of the process as well. In all respects it is necessarily specific in its nature rather than general.

Engineering education is primarily concerned with developing the ability to think efficiently in this definite way and the ability to express one's thoughts clearly.

Engineering Thinking. An engineer's thinking involves in general two processes: *analysis*, or the resolving a situation into more easily understood elements, and *synthesis*, or the combining of the more elementary things into a more complex layout or plan. For example, the estimate of the amount of water power available at a given site, accomplished by securing the area of the water shed, the average and the variations in rainfall, the proportion of runoff for that class of topography, the losses in the stream, the net amount of water that may be expected, the head through which the water would fall, the amount of power lost by friction and other causes, the efficiency of the water wheel, etc., constitutes analysis—a resolution of the whole into its elements. On the contrary, designing and erecting a building of the necessary size, installing hydraulic turbines or boilers and engines of a known operating

efficiency, with the required fuel and water supply, ash-handling equipment, etc., to yield an output of 50,000 hp. is an example of synthesis. Most engineering involves first, analysis or determining the proper procedure based on physical and economic conditions and, second, synthesis or assembling, constructing, and operating the works to attain the desired results.

In *analytical thinking* the engineering student must acquire ability to use certain instrumentalities, such as mathematical relationships and processes, physical and chemical laws, curve plotting, sketching, outlining, laboratory investigations, human characteristics, and cost elements. These constitute his thought material in analysis. In analysis, the student must not only come to recognize the component parts of the whole problem but must discover the quantitative relationships so that he can determine how much each element affects the whole.

In *synthetic thinking*, the engineering student must likewise have a certain amount of thought material. This thought material consists of a knowledge of strength and other properties of structural materials such as steel, cast iron, concrete, and timber, of practical details of pipes, valves, welding, riveting and erection devices, and of the characteristics and costs of commercial products regularly on the market, such as boilers, engines, motors, filters, and conveying equipment.

Analytic thinking, which indicates what is needed in an engineering project, is followed by synthetic thinking, which indicates the procedures required to fill those needs efficiently, durably, and economically.

Expression of Thought. An engineer not only must think efficiently but must be able to convey the results of his thinking to others clearly and concisely. The two

devices that he should master for this purpose are *drawing* and *language* (English) both written and spoken.

English composition is an essential as is drawing in engineering education. The student should consider every class paper an exercise in composition, every speech before a student group or elsewhere an exercise in delivery as well as in content. A speech should have a definite theme capable of succinct statement, made interesting and convincing by expansion and illustration, and then, distinctly, vigorously, and briefly delivered. "Stand up, speak up, and shut up" is an excellent rule for delivery.

Expression of thought in language is so important for an engineer that any amount of time spent in acquiring facility therein will bring a recompense. Efficient thinking and clear expression of thought go hand in hand, the one helping the other. Orderly thinking habits beget orderly writing and speaking habits. If one thinks topically, recognizing the principal issues first and then details coordinated properly under each of the principal issues, he will come naturally to write and speak in a similar manner. Effective expression of thought is second in importance only to efficient thinking itself.

Emotional and Volitional Objectives. In addition to efficient thinking and clear expression of thought, an engineering education has certain objectives of an emotional or volitional character, for the motives and manner of doing a thing are as important educationally as the thing that is done.

In the first place, an engineer should think honestly without bias or prejudice. Usually he does not have a case to prove or a cause to advocate, but rather he has

to work with facts, ascertaining, accepting, and using them as he finds them. Machines, like figures, do not lie, nor are physical laws subject to sophistry or casuistry. A gasoline engine will start if properly adjusted; if essentially in error, it will not start regardless of argument or pleading, either poetic, rhetorical, or profane. The engineer, dealing with undeviating physical laws, must learn to seek true cause and effect relationships, accurate and complete factual information, and to use it as he finds it without shading by his personal inclinations.

For example, the earth stratum upon which an engineer desires to found a structure may not be so stable as he would wish, but he must ascertain how firm it is and design the foundations accordingly. Or, again, an investigation may show that a stream does not afford enough water to warrant a hydroelectric plant; he should abide by the facts and not recommend the erection of the plant regardless of how keenly his client may desire a power plant at that place.

Another volitional objective in education is developing a will to achieve. Setting a high goal of accomplishment may be easier than cultivating the volitional faculties, enthusiasm, industry, and perseverance necessary to attain that goal. Therefore, the student should not accept defeat by a difficult lesson assignment or by an addled laboratory experiment, for such acceptance of defeat merely presages a defeat on a larger scale later in life on a practical engineering project. He should not be completely discouraged by a low test grade but should stiffen his determination and heighten his diligence to retrieve the ground lost. On the other hand, his habitual triumphs over lesson assignments and laboratory experiments make victory the normal and expected

result all through life. He should develop the habit of victory and of discontent with failure.

Since the volitional attributes of industry, initiative, determination, perseverance, courage, aggressiveness, tolerance, and social attitude are developable and improve through discipline and exercise, and since they will contribute to professional success quite as much as intellectual power, they come within the scope of engineering education as properly as do scientific courses of study.

Standards. Not even second to effective mental habits, standards rank as a most important consideration in securing an education. Discontent with any work of a standard of excellence below the best that he can do should be the engineer's mental attitude. Of course, time and expense may compel him to compromise this ideal and to do the best he can in the time and with the funds available, but only the highest standard of performance should bring satisfaction. Such standards of workmanship should be established as a student, for student standards persist as professional standards. The psychological importance of doing a thing right the first time rather than ultimately, after making erroneous trials, cannot be overemphasized. Every time an operation is incorrectly done, an incipient habit forms to do it that way again, making the correct performance all the more difficult.

Standards of workmanship not only should include the student's mental best, but should constitute also his moral best. He should observe accurately, think accurately and honestly, and conclude accurately and honestly in accordance with his observation and his thinking. What he reports as his observation, his thinking, and his conclusions should not be the observations, the thinking,

or the conclusions of another. Careless or "cribbed" performance of class and laboratory exercises may appear a decade or two later in practice as unreliable or dishonest performance of engineering duties. Standards become habitual and not easily modified; standards are not left behind in the classrooms upon graduation; they are carried away even more certainly than is the knowledge of engineering science.

Nothing in the student's work is more important, therefore, than the adoption of and strict adherence to carefulness and integrity as his standards of personal performance, for they inevitably become his life standards.

Professional vs. Liberal Education. A professional education is not in itself a liberal[1] education, but it is in no sense incompatible with or antagonistic to a liberal or cultural education. In fact, a liberal education in this day of expanded knowledge is not a matter of the particular content of a college curriculum but is the result of mental attitudes together with the results of years of study and reflection. While the original "humanities" meant classical learning and contemplated solely facility in graceful and polite expression, the term has come to include many subjects which promote an understanding of human society as well as of literature. A student does not, therefore, acquire culture by a course of study whatever its content; he may acquire a liberal point of

[1] Liberal arts is derived from the Latin *artes liberales*, or freeman's arts, which, among the Romans, only freemen were permitted to pursue. In the Middle Ages, the term *liberal arts* included the seven branches of learning—grammar, logic, rhetoric, arithmetic, geometry, music, and astronomy. At present, liberal-arts colleges include a great variety of courses in more or less specialized and vocationalized groups and have, in the widened scope of knowledge, lost much of their original significance. A liberal education would literally mean a "freeman's education," but it is commonly taken to mean a knowledge of the humanities, particularly languages.

view and certain helpful knowledge that will enable him to read and reflect and thus be enabled to attain to a culture through the years that follow college.

Making a living or achieving a professional success, even in serving society well, is not the only aim of a college education. While a college education may properly aid in attaining these laudable objectives, it should also bring its possessor a richer, fuller, and more victorious life after the living has been provided for; it should bring a discrimination in tastes, a choice of the aesthetic as against the coarse in enjoyments, and a universal rather than a provincial attitude toward mankind. It should represent a mode of living as well as a certain intellectual attainment.

Broadening an Engineering Education. A professional student should seek to liberalize his education wherever feasible. To this end he should take advantage of opportunities to acquire the beginnings of an appreciation of those arts whereby the great souls of the world have sought to express their thoughts and feelings. In the great masterpieces of literature and art, one finds the milestones in man's thinking as well as the revelation of man's motives, devotions, passions, exaltations, and aspirations. These records of man's thoughts and feelings are the most precious heritage of the race, because they most truly represent mankind. An appreciation of the intellectual achievements and of the emotional experiences of man at his best leads to that enrichment of the mind and aesthetic way of living commonly called culture. Begun in college, tastes for liberal thinking and refined enjoyments rather than for pettiness, coarseness, and crudity may naturally grow to fruition through post-college years for the professional man as well as for others.

As objectives in education, culture and civilization should be differentiated. Culture (cultivation of mind and feelings) pertains to the *individual* dissociated from service to society (vocation); by its subjective criteria, it tends to heighten individualism. Civilization (Latin *civilis*, pertaining to society) denotes the total social organization of a *people;* it is gaged by the adequacy of its component institutions—government, laws, newspapers, schools, arts, medicine, religion, markets, money and credit, housing, industries, insurance, transportation, communication, labor unions, business associations, etc. —in achieving the harmony and welfare of mankind. Professional education is designed to serve society and thereby to contribute to civilization. Insofar as culture with humanistic and ethical ideals becomes communal through the aggregate of individuals, it gives intellectual tone to civilization. Patterns of thought and feelings from the most discerning minds of the past are reflected from the pages of history and literature to foreshadow attitudes and actions under new circumstances and, hence, form an illuminated background for all education, professional as well as cultural. Unfortunately, civilization suffers because the undulations of individualistic education, rising and falling with life span, have not advanced the morality of peoples commensurately with the mastery of physical environment under the continuous, cumulative currents of science. As a result, some culturists, overlooking the centuries of war and want under humanistic sway before the advent of technology and viewing the destructiveness of science when politically misdirected, have illogically asserted a moral inferiority for scientific education. It is not the inventor's fault that his devices are at times used to destroy rather than to minister, but the fault of provincial and

intolerant cultures which foster the natural conceits of men and condone the use of political might to attain unjust ends. All types of education should recognize moral purposes and universal values in order that human dignity and social ethics may become ingrained in a nobler civilization.

Knowledge, Inquiry, Observation. Only persistent painstaking effort through the years can bring a mastery of engineering science. The student acquires a beginning in college, and the importance of that beginning can scarcely be overstated, for it is the foundation and the framework for the knowledge later to be acquired. However, this knowledge of established science, even though indispensable, is rather futile without a desire and an ability to make it more complete.

A celebrated philosopher, John Stuart Mill, said a century ago that a danger of education of that day was that it might make disciples rather than inquirers. That danger is still present. It is, perhaps, safe to say that no statement contains the whole truth, and the student's mind should always be alert to discover limitations, exceptions, corollaries, and expansions of any principle encountered. It is also safe to say that *no phenomenon exists in the universe without a cause* and that *nothing occurs in the universe without an effect.* The inquiring mind seeks to discover these cause-and-effect relationships.

Knowledge in itself is not power, contrary to the old aphorism. Knowledge coupled with the techniques of inquiry and observation, and with the faculty to draw correct conclusions from that knowledge, inquiry, and observation, constitutes power.

Most practical engineering projects are resolved only in part by known principles and require for their com-

plete treatment the collection and interpretation of new facts. In other words, the spirit, attitude, and method of research and investigation constitute as vital a part of education as does a knowledge of fundamental science.

The Curriculum. To the student plunging into the details of his first year's lessons, the engineering curriculum may seem to be an assembly of rather unrelated subjects, but such is a mistaken impression. The curriculum is a fairly well unified enterprise, the result of three-quarters of a century of careful consideration.

It contains certain mathematics courses because the laws of nature on which engineering is based are mathematical in principle; science courses—chemistry, physics, mechanics, etc.—to acquaint the student with the particular laws of nature involved in engineering; technological courses as illustrations and as mental exercises in the application of those laws; courses in drafting—the means of conveying concepts to workmen who are to execute them in material form; courses in design as exercises in creative thinking; laboratory courses as exercises in observation and reporting; courses in English and in language as exercises in expressing thought and in understanding the niceties in the thoughts of others; and courses in social studies to show the scheme of social and economic organization into which engineering operations must be fitted and to which the engineer's own life must be adjusted. Although the curriculum appears to be made up of discrete subjects, there is unity in the composite. These subjects have value and purpose only as they contribute to developing the mind and personality of the student for the eventualities of his future. The curriculum might be likened to a steel alloy in which the iron-carbon steel, corresponding to the science-technology subjects, gives essential strength and temper

characteristics, but to which certain metals like nickel and chromium, analogous to humanistic-social studies, are added to refine the grain, improve the appearance, convey its utility, and make its essential character more applicable to human purposes. Even as different metals are used to form a homogeneous amalgam, so different studies combine to form a professional whole, an engineering education, which must not only prepare the engineer to perform his technical work, but enable him to fit that work into the economic uses of civilization and to live his own life enjoyably and cooperatively in society.

Laboratories. The laboratory exercises are primarily designed to supplement and to clarify the text. They are not in the nature of practical training in the manipulation of tools which might be used in commercial work. The objectives of engineering laboratory classes are:

1. To illustrate and vivify certain principles treated in the text.
2. To teach the student to observe phenomena and relationships involved in engineering by checking his observations against established facts.
3. To teach the student to assemble and reduce the data observed, to deduce conclusions, and to make a proper report thereon.

The observations should be complete so that, when the computations have been begun, essential information will not be lacking. The recording should be the originally observed facts, not deductions from these facts, for deductions require careful consideration of all data. The laboratory should supplement the text by developing the student's own powers of observation.

Associations. Never after graduation will a student have so good an opportunity to make friends with many of his fellows whose friendship will be a source of pleasure and profit to him as exists for him in his undergraduate

days. He should make a definite effort to learn the names of fellow students, and what he can of their lives, whether from farm, village, city, and to understand their points of view. He should mentally classify his acquaintances as to qualities that contribute to professional success, and in after years he will be interested and enlightened to compare his student-day judgments with actual developments. He should seek to determine what qualities make Mr. A successful as a student and what qualities make Mr. B unsuccessful. The campus is the student's laboratory in humanity in which his observations and conclusions are of great importance. A student should acquire the art of making and retaining friendships, for that art will contribute potently to his professional success as well as to his enjoyment throughout the years of his practical life. The confidence and friendship of fellow students which are obtained and retained by a sympathetic attitude and uprightness of conduct are open to all college men and should be treasured among the cherished acquisitions of college life.

Engineering Economics. Engineering has for its purpose serving the needs of man. What those needs are and how much mankind, as individuals, as corporations, as cities and other political bodies, is willing and can afford to pay for such service places an economic side to every engineering enterprise; *i.e.*, the engineer usually must pass judgment on two aspects of every project: (1) as to whether it is technically feasible and (2) as to whether it is economically sound.

Analyzing and weighing the economic features of a project is generally the more complex and uncertain part of an engineer's work. Judgment in these matters requires a familiarity with population characteristics, money and credit, methods of stock and bond issues and

other finance procedures, cost accounting, and other phases of economics. The engineering student, therefore, should take advantage of opportunities to become familiar with industrial and economic history and should keep informed concerning current movements in these fields.

Aesthetics in Engineering. From the beginning of his preparation for engineering, the student should endeavor to cultivate a taste for the aesthetic or pleasing treatment of engineering works. Engineering had its origins largely in the utilitarian and the economic; consequently, criticism of the unsightly appearance of the engineer's work is frequently warranted. Steel truss bridges with parallel chords, plain square buildings, smoking chimneys, and other ugly features have been altogether too typical of engineering operations. Beauty in pleasing proportions, in curves rather than angles, in light and shadow effects, in color combinations, in approaches, in vistas, in balance, and in general harmony of design should receive constant attention from the engineer. In automobile bodies, in bathroom fixtures, in bridges, water tanks, highway locations, power plants, and in industrial grounds and buildings, beauty of line, symmetry, and proportion have enhanced the money value in addition to bringing added enjoyment to all who view the work.

No specific instruction in aesthetics included in the curriculum can aid appreciably in the engineer's preparation, because the result is a matter of taste and judgment which come from gradual cultivation. On the one hand, observing engineering works that are pleasing to the eye and determining what makes them so, while, on the other, noting works that are displeasing and the cause of their unsightliness will aid in educating the judgment. The comments of competent critics are

instructive, although the student should examine such comments for their validity rather than unquestioningly accept them as final.

Notwithstanding the difficulties involved in developing an aesthetic sense, the engineering student should begin with his first year in college to undertake this important aspect of his engineering education.

Graduate Study. Within recent years, there has been a tendency to generalize and to liberalize engineering education with a view to making the young graduate more versatile in his employment and more adaptable to social organization as a citizen. At the same time, the greater knowledge requisite for advanced engineering design involved in the more complex operating conditions has accentuated the need for more scientific preparation. In fact, professional engineering in plans and design involves chiefly the research mode of procedure, which is the essential characteristic of graduate study. The result has been a growth in graduate study to meet this enlarging requirement so marked that the graduate students are almost as numerous as were seniors a few decades ago. The number of doctoral degrees conferred annually in the 30 years 1912–1942 increased as follows: in engineering from a few to about 75; in physics from 20 to 175; and in chemistry from 60 to 675. It seems probable that the deficiency in technical personnel at the upper levels will further stimulate graduate study in the years ahead, for the undergraduate curriculum will be preparation primarily for the more routine type of design and for administrative functions.

Some rather fragmentary observations of actual cases lead to the following conclusions: (1) For those in the upper quarter of their class who have an aptitude for creative engineering, graduate study brings higher

salaries and more interesting work sufficient to compensate for the additional scientific preparation; (2) graduate study has relatively little advantage for those not above average in ability. It seems likely that, in the future, graduate study will become the standard preparation for the more professional phases of engineering.

Preparation for Citizenship. As a member of the body politic, an engineer should discharge faithfully and intelligently the responsibilities of a citizen. This is a broad requirement for which no single branch of knowledge constitutes specific preparation. Good citizenship requires personal honesty, obedience to law, devotion to home, fidelity and conscientiousness at work, cooperativeness in neighborhood interests, and performance of civic duty. Like charity, good citizenship begins at home, in one's community and at one's place of business.

Civic duty comprises an intelligent use of suffrage and other processes to promote the effectiveness of local, state, and national government. Local government is the wellspring of all good government, for it is elemental and most directly affects daily life, and from it all higher government flows. Normally, about two-thirds of a municipal budget relates to streets, water, sewers, builders, utilities, and other matters within the purview of the engineer, who should, therefore, have informed opinions on the issues involved. The engineer should not disdain politics, but should vote at all elections, attend political meetings, know party leaders, accept committee work and office when feasible, and feel responsible for the selection of competent officials. He should study the issues in order that he may contribute through discussion to that intelligence of public opinion by which political decisions are made. Civic duty requires dili-

gence to prevent clique actions contrary to general welfare.

Political practices being more relevant than political theory for effective citizenship, and political agencies being subject to the limitations of human capacity and character, the engineer should correctly estimate the human element in politics just as he accepts the workable strengths of physical materials. Since no social situation is ever exactly repeated and every new question must be fitted into the predictable eventualities of the future rather than into a redrawn picture of the past, the engineer should form the habit of keeping abreast of current events and trends. Civilization is being gradually transformed from its feudal heritage into a mold of science through laws and customs predicated on modern technology, which necessarily follow rather than anticipate innovations. Hence, an alert engineer will have a dependable viewpoint for judging proposed measures and should accept his full responsibility as a citizen in a republic, *i.e.*, a representative democracy.

CHAPTER IV

HOW TO STUDY ENGINEERING—GENERAL PROCEDURE

Importance of Good Study Habits. Just as all of a practical engineer's accomplishments should be efficiently performed, so should the engineer's study be efficient. All through his life, the engineer will be required to collect and analyze data, to study existing information as well as the more advanced scientific theories pertaining to his profession. It is highly important, therefore, that he should early develop efficient methods and habits of study.

When a student realizes that his college course in engineering is designed primarily not to give him information but rather to develop his mental powers, he sees the importance of efficiency in his mental activities, and the matter of how he studies becomes perhaps even more important than what he studies. College study not only brings information but it inevitably at the same time brings mental habits, and *these mental habits are likely to be more lasting than the information itself*. Whether those study habits formed in college are direct and efficient or dawdling and inefficient will largely determine whether the engineer will be successful or unsuccessful. The study of engineering differs from that in some other fields in that it is intensive rather than extensive; it aims at a mastery that will make possible the application of the principles involved to secure definite results. Efficient mental habits are, therefore, a primary goal.

Responsibility for Learning Lies with the Student. A student must recognize that learning, like eating, breathing, and assimilating, is a function that everyone must perform for himself and for which he must accept full responsibility. Certain aids such as instructors, laboratories, and libraries are provided; but unless the student is willing to exert himself to take advantage of these aids, he will not learn. The instructor, in addition to teaching, is a clerk who records the degree of accomplishment on the part of the student. If the student fails to accomplish the objectives of a course, the instructor merely records and reports that fact; he does not fail or "flunk" the student; these are intransitive verbs; the student is the one who does the failing. It is important that the student should recognize and accept this responsibility, for an engineer all through his professional life will have to carry certain responsibilities, and this responsibility for student accomplishment is therefore a vital beginning of the habit of responsibility that will form a part of his life.

Cooperation with the Instructor. Whatever the subject matter, the instructor performs three functions generally: he *assigns* lessons or exercises, he *explains* the significance of the matter and the intricacies of difficult details, and he *tests* and records the degree of accomplishment. The cooperation of the student is essential in these three operations if he is to derive the benefit of them. Observations[1] in the Liberal Arts College at the University of Iowa showed that on the average every absence from class reduces a student's success in examinations as measured by his grade. The student should devote himself to the assignment and accomplish it as the instructor directs. Originality is commendable, but

[1] *School and Society*, vol. 33, Mar. 28, 1931.

generally it can best be cultivated after one method is mastered. The student should attend to general explanations and should pursue any difficulties that he may encounter until he finds precisely at what point or points the difficulty lies, so that he can ask the instructor *specific questions* in having the difficulty removed.

The student should devote himself to the tests and understand that they are intended to *reveal to himself* the degree of adequacy of his preparation, quite as much as to the instructor. Unfortunately, tests are at best a sampling and are not always reliable in their indications, but their results should be accepted unless there is conclusive evidence of their unreliability. Students should seek to make good grades, therefore, in order that the tests may be as reliable as possible, and no false modesty should be allowed to prevent a student from achieving excellence.

Study. While a more general definition of study might be given, we shall view it only from the engineering student's standpoint and define it as "the application necessary to acquire and to assimilate ideas portrayed in the textbook."

Reading Is Not Study. Reading is usually only the first step of study. The student may acquire ideas by reading, but to study he must assimilate these ideas, *i.e.*, make them a part of himself so that he can explain and apply them. The ideas are not in the textbook, but in the mind of the author who wrote the text; they are portrayed in the text by symbols, words, and pictures, and such portrayal at best is incomplete because of the limitations of language. The student must grasp the ideas thus inadequately represented and reconstruct them for himself, so that they will be whole and complete in *his* mind in terms of his own experience and vocabu-

lary, as they were in the mind of the author. Four procedures may well be followed in studying a lesson.

1. *Read* the lesson *understandingly.* Read at one effort all that is given in the text pertaining to one part or unit of the subject. Be sure you understand this part, or definitely decide on the points that you cannot grasp, before passing to the next part. Usually a topical paragraph will constitute a practical unit of text for such study. Do not pass a word whose meaning you do not know; look it up in the dictionary. Reading may require half of the time available for the assigned lesson.

2. *Compare* this subject matter with any other similar matter with which you may be familiar. For example, if you have finished reading about the process of making sulphuric acid, compare it with the process of making hydrochloric acid, if you are already familiar with the latter. The second step, *comparing,* may properly receive perhaps one-fifth of the time available.

3. *Illustrate* and *restate.* Study involves digesting and assimilating the content of the text so that you can use it in mental activity just as one digests and assimilates food so that he may use it in physical activity. Try to draw illustrations and examples of the meaning of the text from your own experience. Think of simple homely illustrations. Restate the substance of the paragraph in your own words; state mathematical formulas in words without symbols; recast technically stated principles in nontechnical language, using different wording. Such devices always aid in the assimilating process. Impression is deepened by expression. This third step in study, illustrating and restating, might properly receive about one-fifth of the time available.

4. *Apply* the contents of the paragraph or lesson to a practical situation. The final test of mastery is the ability to apply in solving problems, or in making designs for works or devices. Applying compels a definite *decision* as to one's understanding. One may be able to discuss pro and con the adjustment of a carburetor or the making of certain electrical connections, without being able to perform either operation. Applying is the test of certainty. Engineering study contemplates the application of knowledge to some design or operation. Thinking of applications of the subject matter might receive about one-tenth of the time available.

Thought Material. In order to be able to think effectively and constructively, anyone must have a carefully assorted and classified store of thought material. Much as a mechanic needs an assortment of parts in order to build or to make repairs, an engineer requires assorted and tested thought elements, since constructive thinking consists in putting ideas together in a creative manner.

Thought material comes from (1) one's own experiences and observations and (2) from the communicated ideas of others. The former, if intelligently interpreted are the most completely one's own, but limitations of time compel one to depend on the ideas of others for most of one's thought material.

This thought material must be systematically arranged and filed in one's mind to be effectively usable. This is accomplished by relating the various items to general subjects and filing them under such titles as mathematical processes, materials, mechanics, chemical reactions. Any item of knowledge should be available for use; hence the orderly storage of knowledge requires such a systematic classification.

A college education should bring to the engineer a comprehensive filing system for his thought material in addition to a certain amount of knowledge for the file. His future acquirement will largely consist of amplifying that knowledge, *i.e.*, completing his file. Sometimes, there is a cry raised against "stuffing the mind," but the student may rest assured that the more usable facts that he can assimilate and retain in such a systematic way as to make them readily applicable, the more effective his thinking will be. Moreover, the storage space is elastic and the retention of one fact does not in any way preclude the storage of others. Therefore, the student should

strive to retain as much usable thought material, scientific principles, and general data as possible.

Learning Factual Matter. The human race has accumulated through observation and meditation a vast store of knowledge, which to the student is factual material of an arbitrary and empirical sort. Rational principles may not be involved so as to permit the facts to be reproduced by reasoning. The material must be accepted and learned as it stands. One learns from the printed page in part by reading it but chiefly by *recalling* the content. Indefinitely rereading such material does not fix it in one's mind. The process is somewhat as follows: (1) Read, read, *recall;* (2) read, recall; (3) read, *restate,* REVIEW. These study steps yield corresponding stages in mental grasp that may be characterized as: (1) hazy—clearing—*principal deficiencies revealed;* (2) gaps filled—minor imperfections disclosed; (3) fine points supplied—*completed*—FIXED.

Thinking. The science of correct thinking is called logic; yet the formal study of logic will not necessarily develop power in thinking any more than reading books on physical culture will produce muscular development and coordination. Ability to think comes not from familiarity with a method but rather from the orderly exercise of the thinking faculties.

The indolent reception of ideas either from a lecture or from a printed page is not thinking. It is possible for words from a lecture or from type to pass through one's conscious mind without registering an impression on the mind just as water or sand may pass through a sieve without registering a scratch. The stream of consciousness of the mind runs on continuously like an everflowing river. It may run clear with no burden of thought; it may carry miscellaneous débris of ideas

scattered and unrelated like driftwood; or, by act of the will, it may bring to the mental mill the rafts of thought material in an orderly and directed fashion.

Thinking about a subject consists in correlating and fitting together the pertinent thought material and in bringing into sharp focus the mental image of the situation, in applying one's thought material to a given situation to produce a desired result somewhat as a mechanic would apply his tools, *i.e.*, a wrench of a certain size to turn a given nut, a screwdriver to a screw, etc. Intuitive judgment indicates what to apply, and not infrequently one finds the correct solution after a few trials. This is a conscious effort of the will. Such an effort of the will first concentrates attention on the subject—figuratively, lays it out on the mental workbench—and draws from the shelves of thought material those intellectual appliances and parts necessary to complete and perfect the idea so that it can be formulated for communication to another.

One may reason by drawing general conclusions from a number of particular cases (induction), or one may deduce a specific result by recognizing that it falls under a general principle with which one is already familiar (deduction). Thinking consists sometimes in formulating questions in one's mind and then answering them. There is always a certain amount of subconscious incubation of thoughts which rise to the level of conscious thinking, sometimes automatically and suddenly as "hunches," and sometimes by volitional effort as a phase of the thinking process.

Thinking, therefore, first involves attention and then reasoning and depends for its effectiveness upon the degree of the former and the adequacy and correctness of the latter.

Attention. Study, learning, and thinking are impossible without attention. Nothing is more inimical to these purposes than the tendency of the mind to wander. Efficiency in all mental effort is in direct proportion to the power of attention. The passing automobile, the sound in the corridor, the recollection of the last dance, the anticipation of a "date," the strategy of the lost or of the approaching game, flit across the student's mind and dim the image of the subject under consideration.

Attention can be recalled or compelled by coming back to a sentence, an idea, or a figure of the subject with which one is familiar and which he can readily recognize, especially if that part be interesting or pleasing. Writing down some important statement or word of the subject matter will usually restore attention. Interest, curiosity, novelty, pleasure, help attention, while worry, excitement, and dislike hinder attention.

To keep sustained attention while studying, sit squarely at a table with feet flat on the floor and with a pencil in your hand, underscore important key words and sentences, make marginal notations of supplementary ideas, draw sketches and diagrams which will illustrate the principles of the text. Never attempt to study with the feet elevated on a table or other object. Do not smoke while trying to study; the posture, attending to ashes, etc., prevent sharp attention.

Remembering. Memory is the very heart of learning. Not that one should remember everything, but to be able to remember what one wishes to remember is the basis of learning. A good memory is therefore worth cultivating. Memory is capable of development by *trusting* it and by *using* it, much as a muscle is capable of development. Remembering is of two kinds: (1) verbatim, such as remembering a poem for recitation, and

(2) remembering the substance of the information to be reproduced in one's own words. We are here concerned primarily with the latter.

To remember well, one should:

1. *Learn well* or *overlearn.* To remember better it is necessary to learn better. Work over the subject matter many times after it is fully registered in the mind. Overlearn: learn 50 per cent better than satisfactory.

2. *Recall* frequently. Every time facts are restored to the mind through recalling after they have begun to fade, they are just so much more indelibly fixed; also they fade more slowly. In preparing a lesson on which a recitation will be expected, about two-thirds of the time available should be spent in acquiring the subject matter and one-third in practicing on recalling it to mind, or in reproducing it.

3. Study by topics, keeping the outline of the whole matter in mind and constantly relating the details to the outline.

4. Review the matter and strengthen the knowledge by filling in details.

Drill, or many repetitions, affords the most practical device for "committing to memory" verbatim statements or statistical data. Writing down a portion to be remembered and saying it aloud also helps.

The so-called "hardening period" should be observed. If, after studying a subject, one does not turn immediately to another but continues for a few moments keeping his mind on the same topic and not permitting distractions, such a period will allow the recently acquired knowledge to "sink in" or to "harden," so that it is more perfectly retained.

Improvability. It is probably true that progress in a given subject is not a uniform rate, even though the student devotes the same number of hours each day to that subject. The advance seems to be by rushes, rapid

at first, then slower, rapid again, followed by slower, and so on. This characteristic of improvement rates has been definitely observed in typewriting, telegraphy, adding columns, and in other disconnected operations, and it probably exists in the more complicated learning processes as well. These "plateaus" of progress, as they have been called, are not well understood but perhaps result from a natural cycle of acquiring and assimilating information. The student should not be unduly discouraged, therefore, if at periods of his study, his progress may seem arrested for a time, for he may reasonably expect that, if he persists in his efforts, his progress will again become normal.

Straight Thinking. The phrase *straight thinking*, meaning correct or logical thinking, is widely, but vaguely, used. The phrase implies also direct rather than circuitous thinking. Some requisites of straight thinking may be mentioned.

Open-mindedness, or freedom from bias or prejudice, is perhaps the first essential. To be open-minded, one must be willing to subject his beliefs to scrutiny and questioning. It is a natural human trait for one to believe that whatever pertains to himself is superior. A boy will contend that his dog, however worthless, has unusual virtues, that his home town is the most enterprising, that his home state is the best in the union, that his college is without equal. In a similar way, the natural ego causes us to defend jealously our beliefs on politics, religion, economics, manners, or natural phenomena, and to feel ruffled and irritated at any intimation that these beliefs may not be correct. We resent a mental thrust at our favorite beliefs and conclusions as personally as we would a physical blow on the body. Open-mindedness demands that we separate personal

feelings from our intellectual processes and accept truth from whatever source it may come.

Recognizing true relations between cause and effect is an important factor in clear thinking. Cause and effect seem at times hopelessly mingled. In reporting on the failure of a structure, or on a wreck, the engineer is frequently puzzled to recognize what elements were contributing causes and what were effects. This is particularly the case when there are several causes whose totality produced the result. The distinguishing element is the time, since cause must always precede effect, even by an infinitesimal period of time.

Distinguishing between relevant and irrelevant facts promotes clarity of thought, but the situation may be so complex as to render this distinction exceedingly obscure and difficult.

Giving proper weight or value to evidence that bears on the question is next in importance and results from what can only be termed good judgment.

Errors in analogies may cause fallacies in thinking. Reasoning by analogy is always open to question and should be used only when other procedures are not applicable. The essential principle of the analogous situation must be transferable to the situation at hand.

Another breach of logic is to include the conclusion or a part of the conclusion in the original assumptions without proof and thus to reason in a circle. For example, an essay on "why the steam engine is obsolete" should first show that it is obsolete. Inaccurate and loose diction tends to obscurity, while the use of accurate and specific words promotes correctness in thinking.

There probably is no certain criterion of what is "rational" or "logical" thinking. In general it is the kind of thinking that subsequent events prove to be

correct and would usually be such as would satisfy a group of unbiased and competent persons.

Errors of reasoning are infinite in variety. Reading into language a preconceived idea which the language itself never intended to convey, misinterpreting ambiguous words, "jumping to the conclusion" that a certain event is caused by a given circumstance when the circumstance preceded the event and was capable of causing it even though no direct causal relation is known, and generalizations from one observation are frequent errors in thinking. Another common error is drawing an inference that does not follow from a given set of conditions. For example, concluding that concrete will be permanent because it looks like hard natural rock, or that a certain oil is a better lubricant than another because it burns more freely, or that cast iron is strong in tension because when tested in compression it gives high strength are errors in thinking because the premises are not sufficient to warrant the conclusions. Conclusions, inferences, or deductions must "follow" from a discussion and should contain nothing that is not established in the discussion. Conclusions "follow" when they are supported and no exceptions are discoverable.

Straight, direct, clear, and similar words contrasted with devious, crooked, muddy, cloudy, etc., as applied to thinking, express rather indefinitely a certain general quality of thought in a rather picturesque way in that they transfer descriptive concepts applicable to physical conditions to the intangible concepts of thought. Logical, rational, precise, rigorous, or illogical, fallacious, specious, erroneous, superficial, etc., are more accurately and specifically descriptive of the characteristics of thinking.

CHAPTER V

HOW TO STUDY ENGINEERING—SPECIFIC SUGGESTIONS

Physical Conditions of Study. Irritations, annoyances, or discomforts militate against effective concentration of attention; hence the physical conditions surrounding study are exceedingly important. Even though one is not specifically conscious of such irritations, annoyances, or discomforts, yet they impair attention.

1. The room should be clean, well ventilated, and at comfortable temperature.

2. Chair and table should be at the proper height for the individual. Exceptionally tall or exceptionally short students will be hampered by using chairs and tables of average height. A straight chair only should be used; lounging chairs tend to sloth and drowsiness and should be avoided while studying.

3. The light should be of proper brightness, not too dim or too bright, and should be properly located. Either natural window light or artificial light should come to the student's book or paper from the left rear for right-handed students, and from the right rear for left-handed students.

4. Equipment should be good. Unconscious annoyance from dull pencil, poor paper, unreliable compasses, etc., tend to destroy attention as well as directly to impair effectiveness.

5. Study after real fatigue has occurred is ineffective study. Fancied fatigue may be thrown off and "second wind" attained, after which even greater concentration is possible. Deep breathing for a time or a turn about the room or around the block may be necessary to arouse the faculties from fancied fatigue.

6. Purposeless conversation is an insidious and prodigal waste of time and should not be permitted to interrupt. Social intercourse should be kept to itself and a serious occupation made of study.

The student while studying is working for himself and he should not cheat himself as to time or diligence.

Study Aids. Four devices may be mentioned which aid in keeping attention directed to the task at hand and also in retaining the subject matter in mind.

Underscoring key words and phrases which virtually unlock the meaning of a paragraph aids in grasping the sense and helps later in review by enabling the eye to spot at once the items of importance. To be useful, however, underscoring must be done with discrimination. Promiscuous underlining is confusing and may actually muddle the meaning.

Marginal notes, where such notes indicate the reader's comment, his criticism, or his amplification of the text, are useful. They should supplement underscoring.

Outlining the subject matter as presented in the text brings a comprehensive view of the material. The outline should follow a system that will show the coordination and the subordination of topics and may be done in the margins of the pages, or in a notebook.

Briefing is perhaps the most valuable aid in study. The brief summary of the substance of a chapter may sometimes be placed on vacant space at the end of the chapter, or preferably in a separate notebook. The brief has the merits of an outline, but more than that it should contain important words, quoted sentences of special import, and summarizing sentences stated in the student's own wording.

Observations have amply demonstrated the value of note taking. In examinations, students have been found to answer more than *three times* as many questions when the subject matter was in their notebooks as when it was not.

How to Study Mathematics. The following suggestions on how to study algebra and trigonometry were prepared by Prof. H. L. Rietz, and Prof. Roscoe Woods of the Mathematics Department at the University of Iowa. They are applicable to all mathematics courses and will be found very helpful to students who observe the directions.

A. The first difficulty is that of *reading* the text in college algebra so as to understand the principles to be applied. The student should practice translating formulas into English and vice versa. This will tend to overcome his reading difficulties.

B. Instructions on reading textbook developments in college algebra:

1. Ordinarily begin your study of a topic by reading the textbook for an understanding of principles and methods involved, rather than begin by trying to solve problems in accord with the model illustrative examples.
2. Write out in words and sentences the algebraic statements in the text.
3. When you cannot follow the change from one step to the next, make up a question for the teacher.
4. Try to make good questions to ask yourself and the teacher. Sometimes we hear the statement, "I do not know enough to ask a question," but in the case we are considering you can at least ask why a statement follows from those that precede.
5. The arrangement of work in the formal part of algebra should be carefully studied to expedite the solution of problems. Ordinarily this work is well set up in the text, and it is best to follow the forms given except when you feel you can improve on them.
6. Satisfy yourself as to the truth of algebraic statements by substituting simple numbers for the letters. This has the effect of making the algebraic statements seem real and concrete.
7. Use common-sense judgment as to the plausibility of the results which you obtain in the solution or problems.
8. Do not fail to master each topic in your study of mathe-

matics; the sequential character of the subject renders this important. In other words, a link out of the chain of reasoning spoils the whole chain.

9. Keep a notebook of important explanations by the teacher that supplement the textbook explanations. This notebook may well contain some of the more difficult solutions presented in class.

How to Solve Problems. The following general procedures will be found helpful in solving problems in mathematics, physics, and mechanics:

1. Learn thoroughly the general principles, formulas, and typical solutions given in the text. Merely understanding as you read is not sufficient; be able to reproduce these in substance.
2. Understand what the problem means before beginning its solution. Restate the problem in your own language. Make a complete sketch of the circumstances described in the problem where practicable. A sketch is so helpful that it should become the habitual first step in solving a problem.
3. Write down any assumptions that you may make. Review the text of the principles involved.
4. Arrange all calculations systematically; make legible figures; arithmetical errors frequently arise from mistaking illegible figures; label and underscore intermediate results.
5. Check calculations as you proceed.

How to Study Chemistry. (Suggestions by Prof. Jacob Cornog of the Department of Chemistry, University of Iowa.) Perhaps the feature of studying chemistry that is most peculiar to that subject is the lecture. Few subjects studied by the engineering student retain a general lecture as a part of the instruction, and chemistry is usually one of these few.

The student should take notes on the lecture, which, later in his study, he should rewrite, setting out the main ideas in a connected fashion and with proper emphasis. He should eliminate matter of slight importance. The student should get from the lecture (1)

a general view in proper perspective of the portion covered, *i.e.*, a conception of what constitute the most important parts, and (2) a demonstration from the experiments performed by the lecturer of the theories stated in the text, which should serve as an experimental approach to the subject. The student should not expect to obtain details of information from the lecture; these should be obtained from the textbook, which should be studied in the light of the lecture with emphasis on the material indicated in the lecture as most important.

How to Study English Composition. J. H. Scott, Associate Professor of English and in charge of English for engineering students at the University of Iowa, makes the following comment on studying that subject:

> The actual writing out of the discourse, once under way, should be carried on uninterrupted, with all possible freedom and fluency—the attempt being made to simulate in written discourse all the effects of oral composition. In other words, the message should, as it were, be *talked*—bringing up from the hidden resources of thought the material required, sorting it out, arranging it, clothing it in proper words and sentences—all simultaneously and according to a dozen different patterns, and without interfering with the effect of complete spontaneity in the flow of speech.
>
> Obviously, such being the character of our utterance, literary work requires for its successful prosecution that it be carried on only when the faculties of the mind are operating at rather high efficiency. The putting off of the writing of the English theme into the odds and ends of time at the fag end of the day will be unproductive of satisfactory results.

For most writers and most writing, there must be first an *outline* which indicates the order of development of the theme and the coordinating of its elements. Then, for most writers, there must be a first draft in pencil which will be written rapidly, as fast as the detailed ideas come and the theme evolves. The main

ideas are set down as simple statements and then amplified and expanded so as to make their full meaning, their implications, and scope apparent and their validity acceptable to the reader. The devices most commonly used to expand an idea are (1) examples, (2) comparisons, (3) contrasts, and (4) analogies. A statement of an opinion or belief should be followed by a clause or sentence that will make the opinion seem rational. The first draft should then be corrected and improved as desired by interlineations, additions, and deletions and then copied.

The engineering student should learn to "check" his composition much as he would a drawing in order to ascertain whether or not it is correct as to form. He may observe some minimal essentials as follows:

1. *Words.* Spelling; accuracy of meaning (diction); correct grammatical form; clear antecedents of pronouns; efficiency, or conveying the meaning most completely; avoidance of repeated use of same word.

2. *Sentences.* Grammatical construction, clearness, and form; only one idea in a sentence, even though complex; variety of sentence structure to improve style.

3. *Paragraphs.* Only one topic or aspect of the subject in one paragraph. Does the first sentence of the paragraph open that topic and does the last sentence conclude it?

4. *Whole Composition.* Are the introduction, body, and conclusion distinct and adequate? Is the passage from one aspect of the subject to the next properly indicated by transitional words, phrases, or sentences so that the reader will readily follow? Read the theme aloud. Does it sound well?

For artistic writing, a professional writer may revise, read aloud, and rewrite a composition many times in order to secure not only clarity and correctness but the grace and elegance which he desires. For the engineering student, who is aiming chiefly at clearness and

mechanical correctness, owing to limits of time available, one copying may have to suffice.

How to Study Drawing. Drawing is the unequivocal mode of communicating an engineer's ideas. Written or spoken language may be misunderstood, because speaker and hearer may ascribe different meanings to the words used. Drawing, on the other hand, is an exact instrumentality for conveying thought because its representations are standardized. Lettering of a simple legible style is used instead of script in order that there may be no misreading, even though the drawing be reviewed after many years have elapsed and perhaps after the delineator is no longer available to interpret, explain, or amplify.

The engineering drawing is not a picture but it represents to scale and by dimensioning the *views* that one may have of an object from above, from the front, from the side or end, and by looking at sections cut by planes passed through the object in various ways. Dimensions are indicated by dimension lines and arrows and are related to certain reference lines, usually center lines or axes of the figure. The engineering student must master the use of such devices as "plan," "elevation," "end view," "sections," and "enlarged details."

Since drawings represent views of objects, the student should accustom himself to *seeing the object* in the aspect desired before he begins to delineate it on paper. Students have a tendency to begin a drawing by thinking of the drawing rather than envisioning the object and then representing the necessary views. They should constantly strive for the reverse order of thinking—the object and then the drawing.

Lettering bothers many students and an artist's eye is necessary for superior results. However, anyone, who

has no physical infirmity, can learn to letter acceptably by practice and care. He should follow and practice *one style,* not slant sometimes and vertical at others, or one form of letter at one time, another form at another. He should letter only when he takes time to letter well, using ordinary script for note taking, etc. He may well use odd moments for a little practice on lettering. He should always use guide lines in lettering a drawing.

Professor F. G. Higbee, Head of the Department of Engineering Drawing, University of Iowa, gives the following excellent mode of attack in the study of engineering drawing:

> *First Course.* Study engineering drawing for the purpose of learning the graphical language which engineers use both to record ideas and to convey ideas. Learn not only how to write the language but also how to read it. It is essential to master the principles of graphic spelling and graphic grammar, as well as the art of graphic writing commonly called drawing.
>
> The textbook, which should be studied thoroughly, explains in detail all of these principles; the class lectures review and illustrate them further; and the drawing room problems not only provide opportunity to apply these principles but also furnish ample drill in the "penmanship" of drawing.
>
> Taking notes on points not clear in the text and asking questions about them in the drawing room, taking written and graphic notes in lectures to record essential points, and carefully reviewing and discussing with instructors returned assignments for errors of omission and commission will be of value.

Drawing affords a discipline in clear and exact thinking to a degree probably unexcelled by any other subject, since it requires that each concept be definite before it can be delineated on paper. A line is unambiguous. It is important, therefore, that the student should strive to draw each line precisely right the first time as an expression of a correct concept. Avoid erasures as

much as possible, for they entail loss of time and make the drawing look smeary. A broken line should be so drawn rather than sketched solid and then erased at intervals. To prevent the drawing from becoming soiled, wash triangles and other equipment frequently, cover completed areas of the drawing with a sheet of paper while working on others, and keep the drawing covered when operations are discontinued at night.

How to Pass Examinations. Examinations of one sort or another constitute the chief instrumentality available to an instructor for determining progress on the part of his students. They are so widely used and the student's standing is so dependent upon his success in passing examinations that he should understand their objectives and how best to meet the tests.

An examination may be used to accomplish various purposes, such as:

1. To enable the instructor to ascertain the adequacy of the student's knowledge and of his mental powers.
2. To reveal to the student the adequacy of his preparation and of his study methods.
3. To compel the student to make comprehensive review of the subject matter.
4. To afford an exercise in working efficiently under pressure of time and circumstances.

To pass examinations advantageously, the student should make the following preparation:

1. *Study thoroughly* all term; master each assignment day by day; review weekly; fix the outline of the subject in the mind and relate all details to that outline; give special study to portions which the instructor indicates as being important.
2. *Review systematically* before the examination; outline the whole subject; make sure of important details; but do not cram by working unusual hours the night before the test. The review is almost valueless unless it follows a thorough day-by-day study.

At the examination period, the student will profit by the following suggestions:

1. Bring sharpened pencils, and be ready to begin work at once.
2. Read over the entire list of questions (if available) before answering any, and answer at once those of which you are sure, thereby gaining confidence, and at the same time making sure of getting credit for all that you know.
3. Be sure you *understand the question* before beginning the answer.
4. Do not crowd your answers; leave room for addenda, because frequently more complete answers will occur to you as you proceed with subsequent questions.
5. Carefully *review* your paper and *check* all calculations if time permits. Do not hurry to finish; use the entire period if needed.

Study Planning. An essential feature of all engineering work is that it should be planned so that every aspect shall be provided for properly. This is likewise true of study, which may be considered as an engineering project for the student. A definite clear plan of procedure eliminates many difficulties, hesitations, and indecisions, in addition to making provision for everything.

A study plan is likely to utilize odd periods advantageously. An hour before dinner in the evening, an hour after, a half hour before breakfast, or a period between classes is likely to be frittered away unless the student has determined beforehand what he will do at that time. If the day is carefully budgeted, the student will usually have ample time for his work and moderate recreation.

It is futile to provide a time schedule in great detail, because exigencies and variation in lesson difficulties will necessitate shifts. Hours to be devoted to study should be elastic as to subjects; thus Monday 7 to 11 P.M. might be assigned to mathematics and English without a definite division of time.

Test of an Adequately Prepared Lesson. After an assignment has been prepared, the student should test himself with respect to the adequacy of his preparation. Three grades of adequacy of preparation may be recognized: (1) understood, (2) learned, and (3) mastered. Subject matter is *understood* when the student can read it and immediately explain it. It is not understood until he can explain it in his own words. Mere understanding is insufficient preparation. Subject matter is *learned* when the student has it so well in mind that he can recall and explain it the next day. Most students are content with this degree of preparation. Subject matter is *mastered* when it can be reproduced and explained in all essential points some time—say a month—later. Mastery only is really adequate preparation.

Use of Library. To keep in mind more than a small part of the knowledge necessary for a successful engineer is obviously impossible; hence, it is important to know how to get additional information. Knowing how and where to obtain pertinent material is next in value to having the knowledge in mind. How to use a large library effectively should, therefore, be a part of an engineer's equipment.

The information sought may be in books, bulletins, pamphlets, bound volumes of periodicals, proceedings of technical societies, government documents, engineers' reports, or other documents. In a well-organized library, these are all catalogued and placed on the shelves in a systematic manner.

All volumes are catalogued in the *card index*, and separate articles in periodicals are listed in *periodical indexes*, the chief of which are (1) the "Engineering Index" and (2) the "Industrial Arts Index," both of which may usually be obtained in any engineering li-

brary. The catalogue is arranged alphabetically according to author and title, at least two cards for each item. The card index will serve therefore to guide the student to all volumes and pamphlets.

The volumes are arranged on the shelves according to the Dewey decimal system, which first divides all knowledge 10 groups, each group into 10 subgroups, each subgroup into 10 subsubgroups, etc., so that any work may be given a number that will indicate the subject matter and also a subnumber and letter that indicates the author. The primary divisions are as follows: 0, general works; 1, philosophy; 2, religion; 3, sociology; 4, philology; 5, natural science and mathematics; 6, useful arts; 7, fine arts; 8, literature; 9, history.

Natural science is divided: 500, general; 510, mathematics; 520, astronomy; 530, physics; 540, chemistry; 550, geology; etc.

Useful arts (600) are subdivided as follows: 600, general; 610, medicine, 620, engineering; 650, communication, commerce; 660, chemical technology; 670, manufactures; 680, mechanic trades; 690, building.

Engineering (620) is divided as follows: 620, general; 621, mechanical (including electrical); 622, mining; 623, military; 624, structural; 625, railway and highway; 626, canal; 627, river and harbor; 628, sanitary; 629, other branches. Electrical engineering as a branch of mechanical engineering has a number 621.3. Chemical engineering as a branch of chemical technology has the number 660, while chemistry as a natural science has the number 540.

Cutter's expansive system, used in some libraries, is somewhat similar to the Dewey system except that it employs 26 divisions of knowledge, 26 subdivisions, and

26 further subgroupings, to which letters of the alphabet are successively assigned instead of numbers.

Engineering periodicals comprise many short articles too numerous to be included separately in the card index. The "Engineering Index" and the "Industrial Arts Index" give ready reference to these articles. These indexes for past years are in bound volumes, while current indexes appear in pamphlet form to be collected and bound at the end of the year. In addition to these, there are several special reference indexes for different fields to be found in various libraries.

The engineering student should become familiar with these indexes and with the current periodicals.

Obtaining Employment. In the early years of his career especially, an engineer will usually wish to make application for employment, not only to "get a job," but to get the best job available. The "best job" will not necessarily be the one that pays most at first, but it will be the one that leads most advantageously to the subsequent stages of a successful career. A young engineer should make a correct appraisal of his own qualifications so that the work undertaken may be such as he can perform successfully, for a failure may be construed to indicate incompetence and so block the way to other opportunities. He should formulate the essential information concerning his qualifications in a rather impersonal manner and have a number of copies made, either by mimeograph or otherwise. These copies are then available to enclose in a letter of application or to leave after a personal interview. The form may be somewhat as shown on page 94.

If one knows when he is applying that a position is open, his letter may give in some detail his particular qualifications for that position, such as a mention of his

thesis or any other special study that may bear on the duties involved, a blueprint of a structure or machine that he may have had part in designing, or a sample of his drafting. The letter should contemplate directly the services that the applicant can render the employer, for that will be the latter's viewpoint as he reads the letter. The letter should be addressed personally to the

PERSONAL INFORMATION

Name in full.............................

Address..................Telephone........

Date of birth........Place of birth..........

Height......Weight......Complexion.......

Health............Deformities.............

Drink intoxicants........Gamble..........

Married..........Dependents.............

Church affiliation........................

Paste small photo here

Education: High school......College......Degree......Year.......

Honors........Scholastic rank......Honor society......

Campus activities..................................

Graduate study................Degree......Year.....

Work experience..

References:

Name...................Address...................

proper official with his full title. It should be courteous but should not attempt to flatter the official or his company, although an actual favorable incident might be mentioned. If practicable, the letter should contain an offer to call for a personal interview if the employer so desires. Needless to state, the composition should be without flaw, even if several copyings are necessary. It should not exceed (usually) a page in length.

If one does not know that a position is open, the letter should be in the nature of an inquiry as to whether there

is an opening in prospect and should offer to send more complete information with references if desired. A copy of the personal-information sheet may properly be enclosed with such a letter of inquiry.

A personal interview is the most effective mode to seek employment. Such an interview should be on appointment arranged by telephone or by mail. The applicant should plan with care and in detail what he shall say; he should be prepared to take the initiative in the conversation and to present his case convincingly and completely, expecting the employer, of course, to ask at any time questions which may occur to him. Needless to say, one's personal appearance at such an interview is important: fresh linen, clothes in good taste and press, tie neatly done, shoes polished, nails, shave, and hair in order. Familiarity with the processes involved in the position will help the applicant to talk convincingly, and any exhibit of the applicant's work will lend substance to his remarks. Ready candor in replying to questions is important; an attempt at bluff is likely to misfire; snap judgments in response to questions from the employer are dangerous. When the inevitable question of salary arises, the applicant will do well to offer to accept the regular scale of that position. A cordial "Thank you, Mr. —— for your time and courtesy," whether the results are satisfactory or not, will properly close the interview.

CHAPTER VI

MATERIALS AND STRUCTURES

Introduction. Engineering did not begin with any people or at any definite period; it is coeval with civilization. Engineering progress is a measure of man's subjugation and utilization of his physical environment and might well serve as the framework on which to hang the history of the human race instead of the usual record of kings, dynasties, wars, and treaties. For example, the invention of the steam engine has had a more profound effect on the destinies of civilization and on modes of living than have the acts of any king or the outcome of any war. In addition to contributing to the background of knowledge relating to engineering, the chronicle of engineering, therefore, adds to one's understanding of the history of the race.

The history of engineering clusters rather naturally about certain lines of development:

1. Materials and construction.
2. Transportation.
3. Machines and manufacture.
4. Heat energy.
5. Electrical energy.
6. Communication.

The ancient peoples built prototypes of most of our modern public works, such as canals, irrigation works, waterworks, sewerage and drainage systems, highways, tunnels, bridges, and harbors. The development in construction has been chiefly in materials used, in the

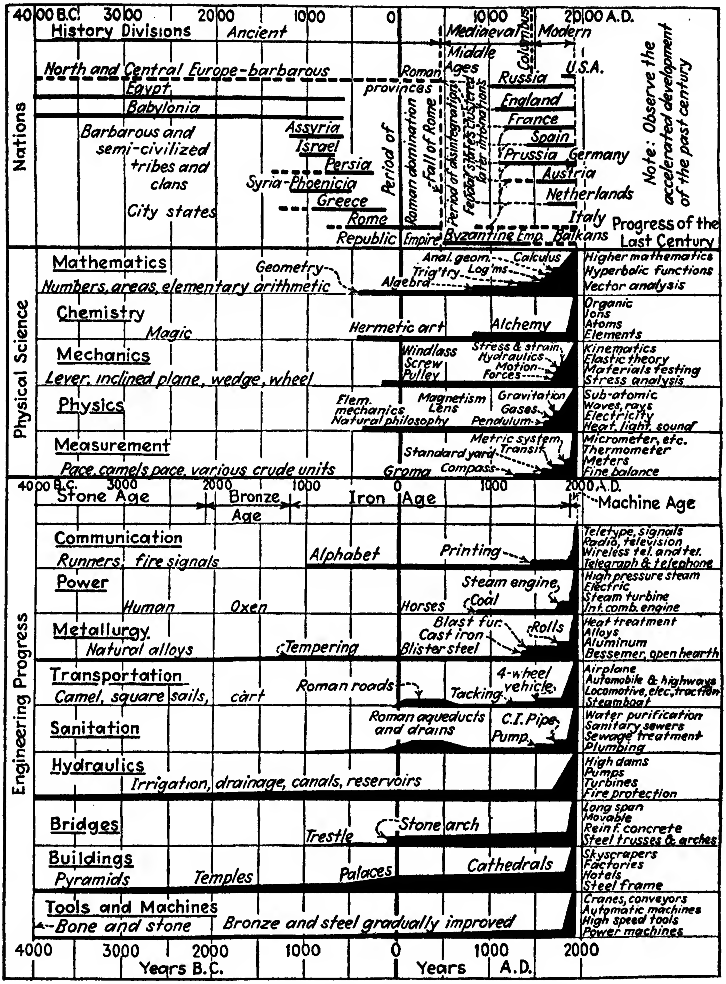


FIG. 9.—Time chart of scientific and engineering development and of technologic ages related to national history. The heritage of Babylonian and Persian achievements in mathematics and arts was passed to Western Europe largely through the Arabs, a relationship not shown in the chart. The developments of the last century presage greater engineering achievements in the future.

knowledge of stress and strains in the materials, in the methods of doing the work, and, most notably of all, in the substitution of mechanical devices to reduce the amount of human labor.

Parallel Development of Engineering and Natural Science. Engineering and natural science have come down through the centuries hand in hand. This relationship is shown in Fig. 9, where the record is correlated to the chronology of certain nations as a time chart in order to give a historical setting for matters mentioned in the text. Dates indicated are necessarily only approximate. Attention is called especially to the great advances in physical science at the close of the eighteenth century, followed by the notable achievements in engineering in the nineteenth century. These advances were paralleled by political and industrial revolutions in nations and in society. The marvelous discoveries in science in the latter part of the nineteenth and the first part of the twentieth centuries may likewise presage far-reaching developments in the technical and industrial worlds.

In engineering development, a very important factor has been the refining of units of measurement and the perfecting of measuring devices. Originally the pace, and the camel's pace for long distances, and the foot, the cubit, the palm, the digit, and the fathom, and other bodily dimensions sufficed for small distances. The evaluation of these crude units of measure into standardized units of precision was a slow process. King Henry VII, by royal decree, declared the yard to be the distance from the end of his nose to the end of his thumb, without specifying the position of either. Queen Elizabeth, his granddaughter, established a brass rod as the standard yard. The original pound was probably

a double handful of grain, but this was later refined to a standard brass weight. Time was roughly measured by some such device as the hour glass until Galileo observed the essential law of the pendulum which made accurate time pieces possible. Units of measurement of light, heat, electricity, sound, and other phenomena have been adopted and refined in the last century, and instruments of measurement perfected. Only in recent years have the microscope, the fine balance, the micrometer, and other instruments of refinement been made available. Their use has contributed much to transforming engineering from an art to a science and to the development of experimental science.

Early Materials. Primitive people were limited chiefly to wood, sun-dried bricks, and stone for building materials, and in the absence of steel tools their methods of shaping, transporting, and erecting were crude and laborious. In building they selected stratified rocks which required a minimum of shaping, which was done by striking with a harder stone. Sun-dried bricks have been uncovered in the arid regions of Egypt and Mesopotamia which, in the absence of freezing temperatures and heavy rainfall, are so well preserved after four thousand years that the inscriptions on them can be read. Straw and grass were sometimes mixed with the clay to give greater tenacity. Kilns for burning brick were invented by the Romans, although reference is made to burning brick at the building of the Tower of Babel,[1] "Let us make brick and burn them thoroughly." Metals were not available in sufficient quantities for structural purposes, other than for tools. Timbers were fitted together and fastened with wooden pins, and by iron nails (after about 1000 B.C.). When

[1] Genesis 11: 3–4.

planning Solomon's Temple, it is stated that the king "prepared iron in abundance for nails for the doors of the gates [hinges] and for the couplings."[1]

Early Construction Methods. Limited knowledge of even simple devices for applying the effort of human labor, which was nearly the sole source of energy in construction, beasts of burden not being used for this purpose, resulted in the employment of masses of men on the construction of public works.

The mechanical devices in use were the lever, the roller, the wedge, and the inclined plane. Such force-multiplying devices as the pulley block, the winch, the derrick (except in simplest form), the crane, the gear train were known only in very elementary form, although they were considerably developed by the Romans. A block of stone, for example, might be dragged on skids, on a sledge, or on rollers, by great teams of men tugging at ropes under the lash of slave drivers. Laborsaving devices were unborn, the only purpose of such simple contrivances as were available being to apply sufficient man power to produce results.

The numbers of men engaged were enormous. Herodotus, the Greek traveler and historian, writing about 450 B.C., related that, according to the tradition of his time, to erect the Great Pyramid (about 3000 B.C.) had required 100,000 men 20 years. Solomon's temple (about 1000 B.C.), an ornate building about 90 ft. long, 30 ft. wide, and 45 ft. high, required 30,000 men in its construction.[2]

Stones were quarried by inserting wedges between lamina of stones or in drilled holes. Sometimes dry

[1] Chronicles 22: 3.
[2] 1 Kings 5: 13.

wooden wedges were inserted and expanded by saturation with water, the expansion cracking the stone.

The tools used were of the simple edge type, chisels, knives, and saws, all of a rather crude form. These were of bronze and iron, and later of steel.

Mining, done entirely by slaves and criminals, was carried on with the most elementary tools, the mallet and wedge. Without props to retain the walls and roof of tunnels and without any means of ventilation, mining was extremely hazardous. Many excavations have revealed skeletons of those who perished in the collapse of the excavation. The crude operations of the ancients were entirely without humanitarian regard for comfort, health, or life itself among the toilers, the slave being considered merely as a beast of burden.

Rope and Cable. So essential to human activities is some form of cordage that, since necessity has been called the mother of invention, it is not surprising to find the beginnings of rope making lost in antiquity. Strips of hide, bark, vines, pliant reeds, and fibrous roots constituted the earliest types of cords. Used originally in their natural form, they were later twisted or woven together for greater strength and increased length. All savage tribes in all parts of the world have made ropes by twisting together the inner bark of trees.

The ancient Egyptians made rope of hides, papyrus, and palm fiber. Pieces of papyrus ropes 3,500 years old have been taken from Egyptian tombs, and ancient engravings show ships with full cordage as early as the sixth century before Christ. Herodotus relates that Xerxes transported his army over the Hellespont (480 B.C.) on a bridge of boats held by cable stretched from shore to shore.

Chains of metal are also of very ancient origin, this being one of the uses of iron even when the available supply was meager.

Copper and Bronze. The existence of metals such as bronze and iron was known to very early peoples, their discovery probably having been made by accident when some savage built his rude fireplace of certain heavy rocks, which proved to be copper or iron ore, and the smelted metal ran down to the bottom of the pit. In fact, relics of these saucer-shaped ingots of impure metal have been found in excavations of camp and village sites of savage tribes in many places.

The early bronzes were the accidental mixtures of metals obtained in this manner, although they were later improved by the admixture of other metals, especially tin. Their crude casting and patient cold-working gave to the implements made therefrom a measure of hardness, but the frequent assertion that the ancients knew a process for tempering copper which is now a "lost art" is highly improbable, since there is no evidence that any of their implements had any characteristics that bronze similarly treated now does not have.

Bronze being the first metal to be used extensively for implements, the stage of culture in which bronze implements and weapons superseded stone and preceded iron, has frequently been called the "bronze age." Knives, chisels, awls, razors, saws, sickles, hammers, daggers, spearheads, and various utensils were made of bronze, which was the natural product, about 90 per cent copper and 10 per cent tin. The bronze age is not a definite period common to all cultures, but for Mediterranean countries it extended from about 2100 to 1200 B.C., when the rapid introduction of iron inaugurated the "iron age."

Nonferrous Metals. Copper, the chief ingredient of bronze, was obtained in relatively pure form from high-grade ores at an early date, the old copper mines around Mount Sinai having been worked probably before 2000 B.C. The Greeks developed a crucible for smelting the copper from the ores into which air could be blown with bellows, thereby extracting pure copper from the copper oxide ore. Copper was widely used for making utensils by those ancient peoples; copper vessels have been found in Egyptian ruins of 4000 B.C.

Lead was likewise known and used by early historic peoples, who discovered the process of removing the lead by roasting the ores. The lead mines in Spain were exploited extensively by the Romans. Lead was widely used for water pipes and for waterproofing.

Zinc, separated from bronze, was unknown to the ancient world and was not fully recognized until about the seventeenth century. Likewise aluminum was unknown until early in the nineteenth century and came into general use only in the twentieth century.

Metals were at first fastened together by riveting, but soldering and welding were used before 700 B.C., welded pieces having been found in ruins dating 1500 B.C.

Iron. Iron was discovered and used by peoples in various parts of the earth at different times. Specimens have been found in Egypt and in India as far back as 2500 B.C., or possibly 5000 B.C., although its extensive use did not begin until about 1800 to 1500 B.C. It was smelted from the ores in crude bloomeries using charcoal as fuel.

A primitive blast furnace for smelting iron consisted of a hole in the ground into which alternate layers of ore and charcoal could be placed and burned. Blowing the fire was a hand bellows at the bottom. By this

means, two men could produce 10 lb. of pig iron per day; a modern blast furnace will produce 500 tons per day. The modern-type blast furnace, a large cupola for conveniently smelting iron from the ores to form pig iron, was developed in Prussia during the first half of the fifteenth century, and cannons were cast in England as early as 1543. Casting from flasks in a manner similar to a modern foundry was invented by Abraham Darby of England in 1708. Cast-iron water mains were first made and used at Versailles, France, in 1685. Cast-iron wheels for railroad wagons (horse drawn) were first made in 1750. Wire drawing was invented in the fifteenth century.

Josiah Wedgwood contributed valuably to the metallurgy of iron by devising in 1782 a pyrometer, depending upon the expansion of a clay rod, which would measure the high temperature of molten iron.

Steel. The improvement in the quality of iron by melting with charcoal, thereby dissolving some carbon in the iron, and by drawing out in the forge was recognized by the ancient ironworkers. The tempering process by quenching in water or oil was known before 400 B.C. However, the knowledge of steel was rather limited until toward the Middle Ages. The famous Damascus steel was probably inferior to that in the cheaper grades of cutlery of the present day. Refined steel for cutlery awaited the seventeenth century.

Steel remained a relatively expensive article until the nineteenth century. In 1754, Henry Cort of England invented the rolling mill for manufacturing structural shapes and railroad rails of iron (later, of steel). The great impetus to steel manufacture came with the invention in 1856 by Henry Bessemer in England of the Bessemer process, by which carbon and impurities are

burned out of molten pig iron and the carbon content of the resulting steel controlled by recarburization. This process made steel so cheap that it replaced wrought iron in structures and in railroad rails. The Bessemer process was not satisfactory with ores of high phosphorus content, and about a decade later Siemens in England devised the Siemens, or open-hearth, process which will successfully burn out the excess phosphorus for making steel from lower grade ores.

The great progress in the manufacture of alloy steels came in the present century. High-speed tool steels, which permit cutting metals at a high rate of speed, and stainless steels (alloys with chromium) are of recent development.

Rubber. Rubber, a product of the sap of the rubber tree, is essentially a hydrocarbon (approximately $C_{10}H_{16}$). Charles Macintosh, a Scottish chemist, first made waterproof rubberized cloth in 1823, and Charles Goodyear vulcanized rubber about 1837 by treating it with a sulphur at a high temperature, thus giving it strength and hardness. R. W. Thompson invented the pneumatic tire in 1845.

Cement. A cement consisting of a volcanic ash and lime ground together, which would set or harden under water (therefore hydraulic), was used by the Romans at the time of the Caesars and continued after that time. An artificial mixture of lime and clay burned and pulverized which would harden under water was invented by John Smeaton about 1760, and a patent calling this product portland cement, because the resulting concrete resembled the rock at Portland, England, was issued in 1824 to Joseph Aspdin.

Reinforced Concrete. The idea of using iron rods inside slender members of ornamental concrete is old,

but the scientific combining of concrete and steel so that the concrete will sustain the compressive stresses (wherein it is strongest) and the steel bars will sustain tensile stress (wherein it is most effective) developed at the close of the nineteenth century. The action by which the reinforcement takes the tension at the bottom of a simple beam and the concrete the compression at the top was explained by two German engineers about 1890. Since that time laboratory investigations and refinement of theoretical analyses have permitted a very extensive use of reinforced concrete in a great variety of structures.

Stress and Elasticity. When a load is applied to a rod, a strut, or other member, the latter is deformed, stretched, or compressed. Each cross section of the member sustains the load, and the force acting on any plane through the member is called the *stress*, the intensity of which is expressed in pounds per square inch. If the member is *elastic*, it returns to normal shape when the load is removed. Analyzing loads, calculating stresses, and proportioning members for the loads to be carried is a fundamental operation in engineering design.

Calculation of Stresses and Strength of Materials. Ancient builders had little conception of mechanics, either the nature of the stresses and strains set up in structural members or of the strength of the materials to resist such stresses. They advanced by trial and error and were guided in their work by the experience of their predecessors. The corbeling effect of stone blocks and bricks and beam action were the main principles of mechanics used in their structures. Although the arch had simple beginnings among the Babylonians, it was greatly advanced by the Romans. Archimedes, the Greek mathematician (250 B.C.), following Aristotle (350 B.C.), was familiar with the lever and the pulley

and the buoyancy in water, but it remained to da Vinci (A.D. 1500) to generalize these principles and to Stevinus (A.D. 1600) to demonstrate the theory of the composition of forces. Galileo explained the laws of falling bodies and laid the first principles of the mechanics of moving bodies. Isaac Newton (A.D. 1687) universalized the laws of motion and introduced the factor *mass*.

Hooke announced the law (1660) of stress and strain, *viz.*, that strain, or deformation, is proportional to the stress or force applied. Further progress was only gradual until Navier, the French engineer, published his epoch-making treatise on stresses in elastic solids in 1821. Stimulated by Navier's work, Saint-Venant in France, Rankine in England, Whipple and Haupt in America, and others developed the theory of structural members in the middle portion of the last century.

The idea of the turning effect of a force, or *moment*, as equal to the force multiplied by the lever arm (= the perpendicular distance from the axis of moments to the line of force) had been explained some centuries before Navier, and Coulomb, a French engineer, had shown (1773) that when a body is at rest all the forces acting are in equilibrium. This gave rise to the following very important principles pertaining to equilibrium:

The sum of all vertical forces = 0, or the up forces = the down forces

The sum of all horizontal forces = 0, or the right forces = the left forces

The sum of moments about any point = 0, or the clockwise moments = the counterclockwise moments.

Engineers and mathematicians had observed that, when a beam (Fig. 10) is bent, vertical lines on the side are pulled apart at the bottom and pressed together at the top. Navier therefore explained that the stress

in upper fibers is compression and that in the lower fibers is tension, and that the maximum stress would occur at the top and bottom surfaces, respectively. He explained also that there is a neutral surface where

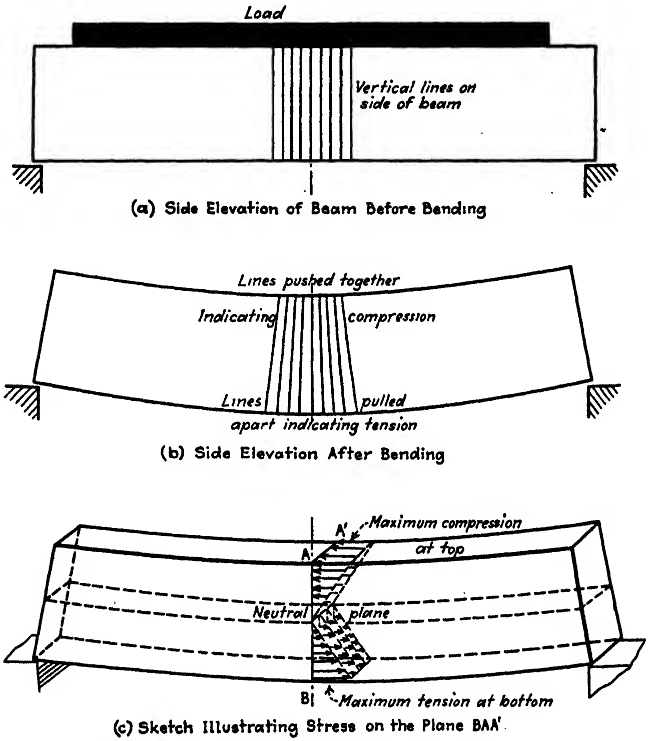


FIG. 10.—Flexural stresses. The nature of flexural stress as a combination of tension on one side of a beam and compression on the other, with shear on vertical sections, was explained chiefly by Navier.

compression changes to tension and that the intensity of the stress varies directly as the distance from this neutral surface.

Testing machines for determining the strength and elastic properties of structural materials were developed

in the last part of the last century, and since 1900 great progress has been made both in theoretical analyses and in the knowledge of the behavior of materials.

Buildings. The temples and other edifices of magnitude built by the ancients were essentially piles of stone, *e.g.*, the Great Pyramid (Egypt, 3000 B.C.), the Parthenon (Greece, 440 B.C.), and the Colosseum (Rome, A.D. 80). Lime mortar was used by the Greeks and hydraulic-cement mortar was introduced by the Romans. Until the Romans devised the arch for long spans and the dome, the distance between columns or supports in buildings was necessarily very limited. Even with these limitations, palaces, theaters, colosseums, and baths were built of magnificant proportions and finish.

Glass was used by the Egyptians at an early day. Glass blowing was invented by the Phoenicians and highly developed by the Romans. Glass panes for windows of considerable size were made by the latter.

Roofing was usually of tile, although wooden roofs were not uncommon.

Private quarters were heated in Mediterranean countries by means of braziers burning charcoal, while public buildings and palaces were heated from central plants consisting of underground furnaces with tunnels leading to the building.

Bridges. Early bridges were of timber in the nature of pile trestles. The Romans, however, built stone-arch bridges of considerable span. Unable to sink piers beneath the water level, they erected the bridge by first diverting the stream and then restoring it to its channel after the bridge was finished. Stone-arch bridges were developed in beauty and size up through the Middle Ages and into the present century, although concrete has largely replaced cut stone because of the lesser cost.

Timber-frame bridges had been used for centuries and, with the development of rolled-iron structural

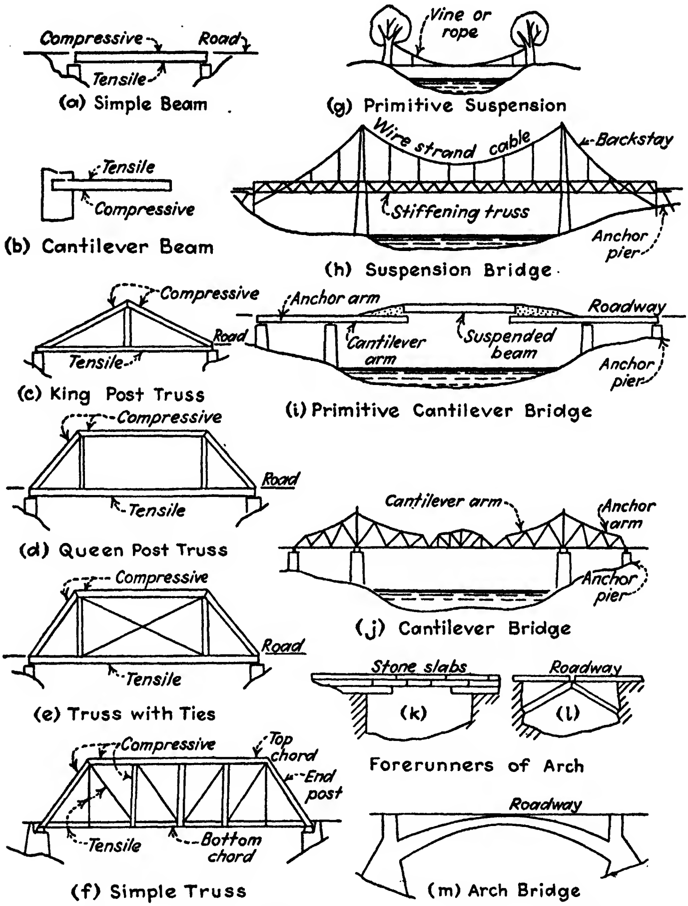


FIG. 11.—Development of bridges. The elements of simple and cantilever beams, and of suspension cables, have been extended to permit bridges to be placed across wide rivers.

shapes, iron-frame or truss bridges naturally superseded timber. Suspension bridges from iron chains apparently originated in India. Squire Whipple in America about

the middle of the nineteenth century wrote a treatise on the calculation of stresses in bridge trusses, which gave an impetus to bridges of that type. In the last half century the development in bridge design has been rapid and is now in process of unprecedented advancement. Figure 11 shows the development of common types of bridges.

Hydraulic Works. The ancients knew little about the behavior of water further than that it ran downhill. But with this meager knowledge they built extensive drainage and irrigation works, city water supplies, and ship canals. Lake Moeris (2200 B.C.) was an impounding reservoir of huge size for irrigation made by diverting some of the flood water of the Nile into a natural depression by means of a canal cut through the hills. A canal connecting the Nile with the Red Sea was begun about 1400 B.C., resumed in 600 B.C., and abandoned after 120,000 men had lost their lives in the excavation. It was finally completed and put into operation by Ptolomy II (300 B.C.). It was 100 ft. wide, 40 ft. deep, and 37 miles long.[1]

The Tigris-Euphrates region was served by a network of canals for irrigation and navigation. Many other such works might be mentioned, but these suffice to show that the ancients had built hydraulic works of considerable magnitude.

Notwithstanding these works, little progress was made in the *science* of hydraulics until the latter part of the eighteenth century when Antoine Chézy, a French engineer, explained (1775) the principles governing the flow of water in open channels. Galileo had said that he "found less difficulty in the discovery of the motion of the planets, in spite of their amazing distances, than

[1] GEST, A. P., "Engineering," p. 13.

in investigations of the flow of waters in rivers which takes place before my very eyes." Experimentation of the last part of the nineteenth century and in the twentieth century has advanced the science of hydraulics as well as the application in hydraulic engineering.

The ancient Romans were acquainted with and used the simple float waterwheel to pump water, but probably for no other purpose. The undershot wheel was a development of middle European history, the overshot wheel somewhat later, and the turbine chiefly in the latter part of the nineteenth century, although a forerunner of the turbine was used at an earlier date.[1] An extensive plant of undershot wheels, built in 1664–1685 to pump water for the famous Versailles gardens (France), remained in use until replaced by steam engines about 1803. The old float wheel had an efficiency of about 5 per cent, the undershot wheel 20 per cent, the overshot wheel 60 per cent, and the modern turbine about 90 per cent.

Public Water Supplies. Public water supplies for cities were built by many of the ancient peoples, those of the Romans being the most elaborate. Without the use of large pipes or any other sort of conduit that would carry water under pressure, the builders were compelled to convey water by gravity at an elevation always above that of the users. The ruins of many of the old masonry aqueducts which conveyed water to imperial Rome still stand on the plain around the present city. The water was commonly delivered to cisterns from which it was carried in pottery vessels by the people, although it was conveyed through lead or clay pipes to the houses of the wealthy. Settling of impurities during storage was the only kind of purification

[1] *Power*, vol. 74, p. 502, Oct. 6, 1931.

known, and because of aquatic growth and inevitable pollution, the quality was poor. The sources of supply were usually mountain streams or lakes.

No marked improvements occurred in water supplies, except that the introduction of cast-iron pipe and of steam pump facilitated securing a more satisfactory supply, until near the end of the nineteenth century, after the discovery of bacteria as the cause of infectious diseases borne by water. The use of sand filters for removing disease-producing bacteria originated in Europe about 1890 and developed rapidly there and in America. A sand filter consists essentially of large beds of sand with underdrains through which the water passes. The original filters covered large beds and purified only about 5,000,000 gal. per acre per day, the filters being laid dry and cleaned perhaps once or twice a year. More recently in America, the rapid sand filter, which purifies 125,000,000 gal. per acre per day, has come into almost universal use. These are built in tanks, and the sand is cleaned by agitation and washing with clear water every day or so. The introduction of chlorine into water for the purpose of killing bacteria has been developed chiefly since 1915.

City Sanitation. The ancient peoples built sewers and drains for carrying away ground water, waste water, and storm water at an early date. The Cloaca Maxima, or Great Sewer, built perhaps as early as 600 B.C. to drain the marshy land between the hills of Rome, is still in use. It is about 10 ft. across at the outlet and receives the contributions from many smaller tributaries. It is built of large blocks of lava stone without mortar, the top being arched.

Sanitary sewage was not carried in the sewers of the ancients or of the mid centuries. Domestic wastes were

thrown into the streets and carted away. Until the nineteenth century, laws quite generally prohibited the discharge of sanitary sewage into the sewers. Latrines, cesspools, and the streets served all sanitary uses.

Sewers carrying sanitary sewage with drainage water and discharging into natural watercourses were in use early in the nineteenth century. The successful construction of separate sewers for sanitary wastes at Memphis by George E. Waring (1880) was an epochal achievement, for it made possible the treatment of such sewage before discharge into natural waters. (Separate systems had been proposed previously by others.)

Sewage treatment is for the purpose of removing organic matter and consists chiefly of partial sedimentation of decomposable wastes, such as fecal matter, and allowing the settled solids to decompose. The septic tank, the Imhoff tank, and separate digestion tanks and the activated sludge process are recent inventions to achieve this end. If further treatment is necessary, the effluent, after the larger solids have settled out, is run through coarse filters of gravel or crushed stone where partial oxidation of remaining organic matter occurs. All of these are developments of the twentieth century.

Tunnels. Ancient tunnels were practically limited to excavating through rock, owing to the lack of means of supporting the sides and roof of a tunnel in ordinary soil. The excavation was done by means of hand tools, and the spoil was carried out by men, explosives being unknown. Workmen perished by the thousands. The Romans introduced timbering in an elementary way, together with adits and ventilating shafts. Gunpowder was introduced in tunnel work in 1613 by Martin Weigel

in Germany. Tunnels for canals and highways began to be built in the seventeenth century, and railroad tunnels came with railroads. Machines for rock drilling were introduced early in the last century. The longest rock tunnels of large size are the St. Gotthard (9.3 miles) and Simplon (12.5 miles), both between Switzerland and Italy.

The invention of the shield (1800) for submarine tunnels caused tunnels under wide rivers to be built to carry railway and highway traffic. The shield is a large iron cylinder, the size of the tunnel, which is pushed forward into the earth by means of jacks; the inclosed earth is removed, the lining extended, and the operation repeated. The work is done under pneumatic pressure to exclude the water. More recently, various tunneling machines have been invented which expedite and cheapen the work.

CHAPTER VII

MACHINES AND MANUFACTURES

Introduction. Machines represent devices for performing work with less effort on the part of man. Original man had only his hands, but he soon discovered the utility of a lever for moving stones and logs. The earliest tools were of wood, bone, and stone, and prototypes of edge and boring tools, hammers, etc., made of these materials have been found by archeologists among the relics of earliest man. The common hand tools, chisel, saw, scraper, drawknife, and even a crude lathe are of great antiquity. Tools were gradually improved as better materials became available. Aristotle, the Greek scientist (350 B.C.), explained the applications of the lever, tongs, the wedge, the winch, the roller, the pulley, and perhaps the friction wheel. The toothed wheel, the forerunner of gearing, is described by Vitruvius ("Ten Books of Architecture") at the time of Augustus Caesar. Gearing awaited the arrival of improved iron.

Developments in machines were negligible until about the close of the eighteenth and the beginning of the nineteenth century, which was a period of great intellectual activity, both scientific and political. The invention of the steam engine gave an impetus to the invention of machines for the application of power. Also the invention of cast iron and of processes for cheaper wrought iron afforded materials which made such machines practicable. The development of laborsaving

INVENTIONS

Invention	Date	Inventor	Country
Weaving shuttle	1733	John Kay	England
Spinning jenny	1763	James Hargreaves	England
Steam engine	1769	James Watt	Scotland
Circular "saw"	1777	Samuel Miller	England
Grain thresher	1788	A. Meikle	England
Rotary press	1790	William Nicholson	England
Planer for wood	1791	S. Bentham	England
Cotton gin	1794	Eli Whitney	United States
Continuous paper web	1800	L. Robert	France
Wood mortiser	1801	M. J. Brunel	England
Planing machine	1802	J. Branch	England
Electroplating	1805	L. Brugnatelli	Italy
Knitting machine	1806	Jeandean	France
Band saw	1808	William Newberry	England
Lathe for irregular forms	1819	Thomas Blanchard	England
Hot air blast	1828	J. B. Neilson	Scotland
Type casting and setting	1828	Henry James	England
Toothed sickle	1833	O. Hussey	United States
Reaper	1834	C. H. McCormick	United States
Steam hammer	1842	James Nasmyth	Scotland
Sewing machine	1846	Elias Howe	United States
Shoe sewing	1861	George McKay	United States
Well driving	1861	N. W. Green	United States
Passenger elevator	1861	E. G. Otis	United States
Typewriter	1860	C. L. Sholes	United States
Pneumatic drill	1871	S. Ingersoll	United States
Air brake	1872	George Westinghouse	United States
Roller flour mills	1875	S. Wegmann	United States
Gas engine	1877	N. A. Otto	Germany
Linotype	1884	O. Morgenthaler	United States
Electric welding	1886	E. Thompson	United States
Steam turbine	1891	C. A. Parsons	England
High-speed steels	1900	Taylor and White	United States

machines is indicated in the list of inventions of the preceding table.

Woodworking Machines. The hand tools used in woodworking were so simple and inexpensive that

individual woodworking shops prevailed until a relatively late date. Cabinet, carpenter, cooperage, carriage, and furniture shops were widespread where master and apprentices worked. While a crude lathe, operated by a cord pulled back and forth or by a treadle, was an old device, woodworking machinery practically did not exist before the nineteenth century. Samuel Miller invented the circular saw in 1777 and William Newberry the band saw in 1808, the latter saving much in the ~~width of the kerf waste.~~

The lathe for turning irregular pieces, invented by Thomas Blanchard in 1819, was made automatic by C. Mattison, of Rockford, Ill., some decades later. Machines for scraping, sanding, mortising, tenoning, and veneering of recent years have greatly advanced wood manufactures.

Metalworking Machines. Following the middle of the last century, the old-time forge and anvil gave way to the power hammer and press, but the notable changes have occurred in the present century. The engine lathe has developed in precision to a most remarkable degree. The development of the steam engine compelled the improvement of the lathe because engine cylinders had to be turned smooth and true inside. The planer, the drill, the milling machine, the gear cutter, and others have all made progress in design, but the notable innovations are the machines for multiple and automatic operation, which, with one setting, make many identical parts and eliminate human attention.[1] Ambrose Swasey invented the epicycloidal milling machine for cutting gears late in the century. The improvement in micrometer gages and in lubricating oils from petroleum (instead

[1] The student will best obtain a conception of these machines by visiting the shop's laboratories and observing their operation.

of animal fat) are two factors that have greatly influenced the development of machine tools (see Fig. 12).[1]

Special machines include groovers, broachers, reamers, tappers, nibblers, jigs, threaders, grinders, gear cutters, and others.

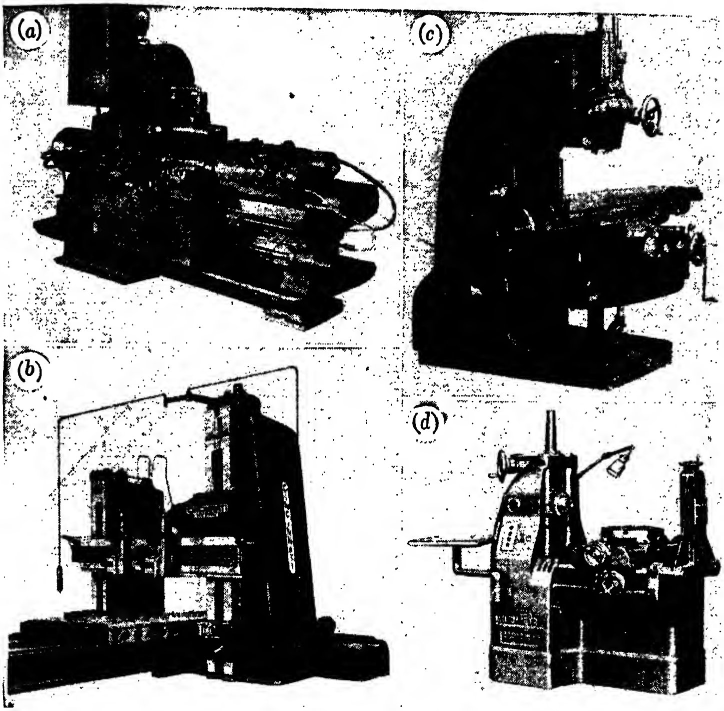


FIG. 12.—Typical metalworking machines or machine tools: (*a*) lathe for turning and facing; (*b*) planer for surfacing and scarfing; (*c*) milling machine for cutting and shaping; (*d*) autometric precision boring machine for drilling, reaming, and threading.

Fabrics and Leather-working Machines. Weaving and knitting by hand are ancient arts, but the nineteenth century with machine methods made fabrics so cheap that even the poor can have good clothes. Spinning

[1] Courtesy of Seneca Falls Machine Company, Cincinnati Planer Company, and Kearney & Trecker Corporation, Milwaukee.

cotton, wool, or flax into thread, weaving into cloth, cutting into garments, and sewing the seams are now all done by multiple-operation machinery. Fabrics, rugs, and draperies with intricate patterns are woven by machines. In a similar way, shoes are cut and sewed by machines, thereby producing cheaper and better shoes and at the same time reducing the number of hours of toil for a day's wage.

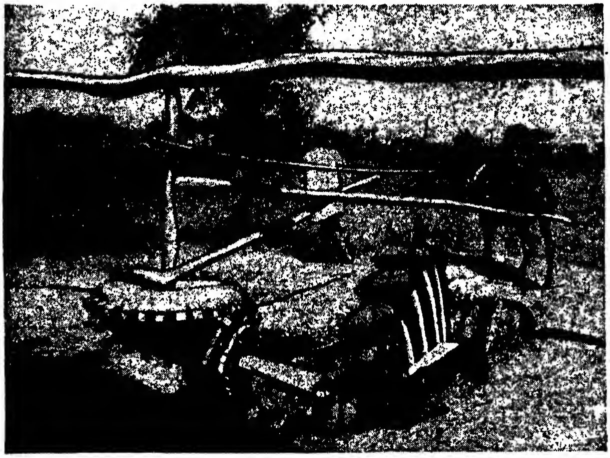


FIG. 13.—Primitive horse gear for pumping water. The peg-tooth wheel was the ancestor of the modern gear wheel.

Material-handling Machinery. The drudgery of human toil has always been the routine handling of materials, and in the past half century engineering has done much to relieve that drudgery. The line conveyor for assembly work, the continuous-chain conveyor for processing, crane unloaders, belt conveyors on board ship, drag lines, pneumatic drills and conveyors, tractors, electromagnets for handling iron and steel, live rolls, car unloaders, clamshell grab buckets, steam shovels, and other devices eliminate the drudgery of modern industrial operations.

Pumps. The only methods of elevating water known to the ancients consisted of a pail on a lever, the Archimedes screw, and buckets on a rotating wheel driven by a treadmill or a float water wheel, although a crude sort of pump was devised about 120 B.C. The cylinder plunger pump came into use in the late Middle Ages. The first practical use of the steam engine was to pump water. This occurred in the memorable year 1776 in England. In fact, the only use contemplated for the first steam engines was to pump water from coal mines.

Flywheel piston pumps, introduced by Holly in 1871, greatly improved the efficiency of the cylinder pump. Henry R. Worthington and others did much to improve steam pumps. Centrifugal pumps have been so improved that they will raise huge quantities of water or pump against high pressure heads, with an efficiency of 80 to 90 per cent.

Hydraulic Turbines. The old water wheel has been replaced entirely by the modern hydraulic turbine, which will now operate at over 90 per cent efficiency. The earliest reaction turbine was made by Fourneyron (1827) in France. James B. Francis, an American engineer, contributed much to the development of the turbine during the middle decades of the nineteenth century, and various manufacturing concerns have further developed it in recent years. L. A. Pelton, a California engineer, invented an unusually successful impulse wheel for use under high head.

Steel Rolling Mills. Henry Cort, a shipbuilder of London, devised (1783) steam-driven steel rollers to roll white-hot iron into shapes, plates, beams, etc., to replace the old method of hammering. A few years later, he also invented the reverberatory furnace, in which the iron was not heated in contact with the fuel, but the

flames were made to "reverberate" from the roof of the furnace down to the metal. In 1842, James Nasmyth invented the power-driven hammer; and about the same time John Fritz invented the three high roller and made many other improvements in steel manufacture. The great centers of iron and steel industry in America are now located at Pittsburgh, Bethlehem, Buffalo, the Chicago region, and Birmingham, Ala.

Steel manufacture has been characterized in recent years by a refinement of metallurgy and of chemical control and by the reduction in the amount of human labor involved.

Instruments, Computing and Recording Machines. The development of speedometers, service meters, gyroscopes, stroboscopes, controls, business machines, and other types of instruments has come to occupy the genius of many engineers. Machines for computing the times of tides, for routine addition, multiplication, and division, for registering cash received, and for bookkeeping have greatly reduced the labor of accounting and clerking. The devising of such instruments and machines has become an important phase of engineering.

Factors of Production. Not only in the design of machines and plant layout, but also in correlating the forces of industry will the principles of engineering be applied. Industrial organization involves four essential factors which must be properly coordinated for economic production:

1. Capital: land, plant, equipment, working funds, risk.
2. Management: executive officers, plant managers, with their technical, legal, accounting, and sales staffs.
3. Supervisory personnel: superintendents and foremen.
4. Labor: skilled and unskilled.

Under simple handicraft manufacture, the owner embodied capital, supervision, and often a portion of the

labor, so that the relations between management and labor were personal and intimate. The position of the worker, granted good performance, was virtually as secure as that of the owner. Large-scale production, resulting from technological processes, necessitates comprehensive organization with a classification of functions and personnel. Socially healthy industrial organization would harmonize the interests of all, free from the vagaries of politics and with a view to optimum public service.

Capital constitutes accummulated savings, and its owners can be attracted to invest in industry only by the hope of a return on the investment, either as interest on bonds or as dividends on stock of the corporation, which owns the plant. The risk of failure is borne by the stockholders, since the bondholders receive a stipulated rate of interest, officials and managers receive definite salaries, and labor receives wages at accepted rates.

One corporation may own many plants. The stockholders are represented by the board of directors. The executive officials comprise a president, a number of vice-presidents in charge of various phases of operations, a secretary, and a treasurer. A manager is in charge of operations at each plant. Officials and managers are permanently employed on annual salaries.

Supervisory personnel consists of superintendents of departments and foremen of operating processes, usually employed on a monthly or weekly salary, with tenure dependent somewhat on periodic business activity. Supervisory personnel are nominally a part of the permanent organization and commonly side with management in labor disputes.

Labor, employed at daily or hourly rates of wages, expands and contracts with seasonal and other fluctua-

tions in business, although skilled workmen are continued with as much regularity as possible, since they have an investment in their skills. Labor is now commonly unionized, and industries operate either closed shop (entirely union) or open shop (union optional). The local union is normally a part of an international, which is usually affiliated with one of the comprehensive organizations, whose aim is to promote the political interests of the labor groups, so that collective bargaining with a single employer has ceased to be the chief purpose of union membership.

The ultimate interests of all groups are served when the company's business is prosperous by virtue of constancy of operations and freedom from losses, but labor organizations with coercive techniques and political action programs negate that unity of interests. To procure full cooperation through fairness of regulations and decisions, human understanding, and clarity of policy is perhaps the supreme test of management. Security in employment with a personal sense of importance in operations is the key to identifying the interests of the worker with those of the company; hence, the more the year-round employment and employee recognition, the greater the attachment of the workers to the company. Mechanization, especially the present introduction of electronic controls, tends to eliminate casual labor, to enhance human judgment in operations and thereby to promote permanency of employment and reliability of service.

Engineers frequently progress through operating positions to the responsibilities of management, for which many qualifications other than technical are requisite, but for which well-rounded engineering training is a good foundation.

CHAPTER VIII

HEAT ENERGY

Source of Energy. The original source of energy which the engineer applies is the sun. Whether that energy has been made available by the sun's evaporating water from the ocean, moving the winds to carry the vapor to the heights from which to turn water wheels on its way back to the sea, or by storing through vegetative life the carbonaceous material of the coal measures, or by building up the combustible hydrocarbons of petroleum and natural gas, the energy available can be traced back to the sun as the primary source. In all probability this energy was transmitted from the sun to the earth chiefly in the form of heat. The history of mankind is being greatly influenced in the present era by the extent to which that energy is utilized.

Energy is the property of being able to do work. Heat is one form of energy which is utilized by means of so-called "heat engines" (*i.e.*, steam and internal combustion) for doing work, such as running machines. A body, water, air, or other gas in motion possesses energy because it may do work in giving up that energy. Water at an elevation possesses energy by virtue of its height and the pull of gravity. Steam engines, steam turbines, gasoline or other internal-combustion engines merely convert, through the agency of steam or other gas, the heat from burning the fuel into the mechanical energy of moving piston and rotating wheels. Animals were the only source of energy utilized by the ancients, except a

little water power. Animals were used, prior to the steam engine, not only for pulling directly but also on treadmills and on various other types of power gear for pumping water and operating mills.

The Chronicle of Fire. The discovery of fire back in the prehistoric (preglacial) ages was an epoch-making event. Of course, it was discovered independently by savage men in various parts of the world, and the customary worship of fire not only indicated its benefit to those savage tribes but also afforded a flickering forecast of the indispensable part that fire was to have in the evolving civilization of the race. Well might savage man bow in adoration to this mighty force, for it was destined to bring him physical comfort and personal prowess! Figure 14 shows the consumption of various fuels in the United States since 1880.

Coal. Coal was unknown to the ancient world, the fuel of that time being wood and charcoal. Formed back in the early geologic ages from the dense vegetation that covered the earth at that time, it lay under the successive layers of rock and soil which covered it until man had sufficiently advanced in intelligence to be able to use it advantageously. Of just when and how coal was first discovered to be combustible there is no record. It probably was first discovered in England, for there is record of its use there as early as about A.D. 850. Its use was prohibited by royal edict as late as A.D. 1200 because of the smudge, but the growing scarcity of wood caused its use to increase, nevertheless. Bituminous coal contains carbon, tar (bitumen), and gases as combustible elements and a certain amount of mineral matter as ash; anthracite contains carbon and ash.

While North America surpasses all other continents in its coal supply, coal is widely distributed. The exten-

sive coal beds of Great Britain largely account for her lead in industrial development, and France has developed coal fields in an industrial area. The heat value of coal, as well as of other fuels, is commonly measured in B.t.u. (British thermal unit), which is the amount of heat required to raise the temperature of 1 lb. of water

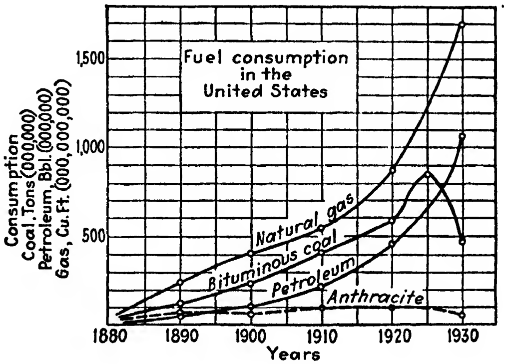


FIG. 14.—Consumption of various fuels in the United States. Fuels constitute the chief source of energy, which is first generated as heat and then converted to electric or to other forms of energy.

1°F. A pound of good coal contains about 12,000 to 14,000 B.t.u.

Petroleum. The word petroleum means *rock oil.* It is a complex mixture of a large number of "oils" (hydrocarbons, C_nH_{2n}, C_nH_{2n-2}, or C_nH_{2n+2}) which can be separated into groups by distillation. It was known in a small way to the ancients; bitumen, pitch, or asphalt was used as a plaster at an early time, as shown in the explorations of Nineveh and Babylon. The petroleum spring in western New York was discovered by a French missionary in 1627, and others were later found in Pennsylvania. The Indians used these oils as fuel for their fires. Drilling for artesian wells revealed the existence of petroleum in the Ohio Valley, particularly

in Cumberland County, Ky., in 1829. The famous Drake well, the first in history, came into production August 28, 1859, and during the remainder of the century drilling wells and refining the oil became a definite industry, which has spread to the Southwestern States and to the entire world.

Petroleum at first was refined by comparatively simple distillation processes, the lighter oils (those most readily volatilized) being given off as vapor and condensed first. The usable part of the petroleum was at first the intermediate oil, commonly called *coal oil* or *kerosene*, both the lighter gasoline and the heavier oils being considered as waste products. With the invention of the gasoline engine, gasoline became the important part of petroleum, and also with the new chemistry engineers found ways to utilize the heavier oils and the solid residue. The solid residue of some petroleums is paraffin, and of others it is asphalt. In general, the petroleums from the eastern United States have a paraffin base, while those from the Southwest are asphaltic and those of the mid-continent fields are mixed.

Petroleum products as fuel and lubrication are used by the mechanical engineer, while other products are used by the chemical engineer for a great variety of purposes. The asphaltic residue (hydrocarbons in which n in the formula is of about the magnitude of 20 or more) of asphaltic petroleums is used by the civil engineer for paving, waterproofing structures, and other similar purposes.

Gasoline. The lightest, or most volatile, group of "oils" or hydrocarbons given off in distillation is called gasoline (benzine, naphtha, or petrol). It has a specific gravity ranging approximately from 0.590 to 0.759. Commercial gasolines have a specific gravity of 0.728

to 0.759 at 60°F., while the lighter products, ranging from 0.695 to 0.705, are used for aviation. The second fractional group is commonly called kerosene, the third is "fuel oil," and then come the "lubricating oils." The residue contains asphalt or paraffin, depending upon the original character of the petroleum, and there finally remains the free carbon or coke.

When gasoline engines became so widely used, the demand for gasoline exceeded the amount naturally available from petroleum and, in 1913, the "cracking" process was invented, by which the heavier distillates are subjected to high pressure and heat, thereby "cracking" the molecule and converting the heavier hydrocarbons into the lighter. Also, within recent years, much gasoline is derived from gas wells as "casing-head" gasoline. It comes up with natural gas from gas wells and is recovered at the top of the well. In 1928, Dr. Karl Krauch published his method of making gasoline by the hydrogenation of coal, an invention by Bergius whose practical significance is yet to be learned.

The quality of gasoline is rated on the "octane scale" between octane (C_8H_{18}), which never knocks, as 100, and heptane (C_7H_{16}), which always knocks, as zero; *e.g.*, an "octane number" 80 indicates good gasoline.

Gas. Gas for heating or lighting, usually consisting of a mixture of combustible gases, has been used for a century and a half. It may be a natural product from a gas well, or it may be manufactured as water gas or as coal gas. Water gas is made by applying steam to coal at incandescent temperature, while coal gas is obtained by the distillation of bituminous coal. More recently, gas is made as water gas from fuel oil. William Murdoch, one of the early inventors of a locomotive, first used gas for illumination about 1792. Gas lighting of houses

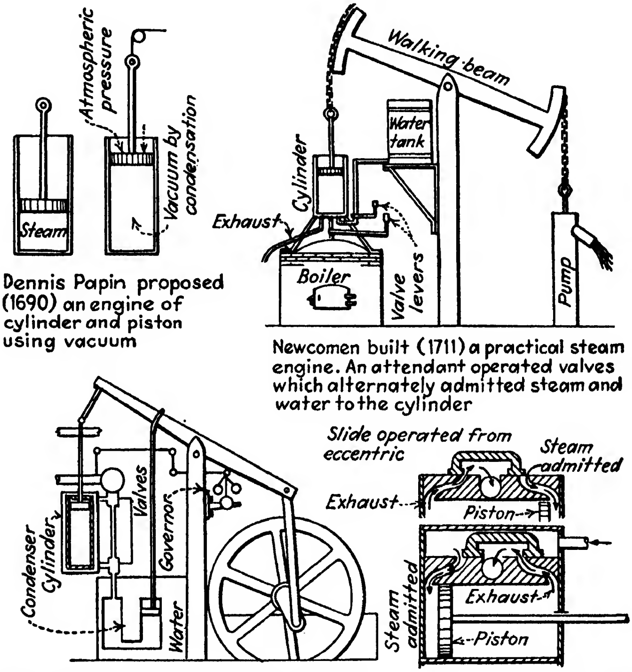
and of streets became standard practice until replaced by electricity about the beginning of the twentieth century. Gas works since that time have been devoted to heating.

Steam Engine. Crude conceptions of an engine to apply the energy of steam to doing useful work existed a hundred years before a practical steam engine was invented. Thomas Newcomen constructed an atmospheric steam engine in 1711 which created a vacuum on one side of a piston by suddenly condensing the steam and allowing atmospheric pressure to push the piston. All such engines were called "fire engines." Their utilization had caused a considerable development in steam boilers even before the time of Newcomen.

It remained to James Watt, however, an apprenticed instrument maker, to invent the practical steam engine which utilizes the expansive power of the steam. After his instrument-maker apprenticeship in London, Watt, as a young man, returned to Glasgow, but owing to the fact that his apprenticeship had been outside the borough the guild would not permit him to set up a shop for himself. The guild thereby unwittingly conferred a great benefit on mankind. He was then engaged to repair some apparatus for the University of Glasgow, among which was a Newcomen engine. In making the repairs, he hit upon the idea of his condensing steam engine, which he patented in 1769.

The Newcomen engine, as well as the Savery which preceded it, condensed the steam in the cylinder by introducing cold water after each stroke, thus cooling the cylinder and causing a heavy loss of efficiency. By condensing the steam in a separate chamber, Watt made the steam engine practical through the increased efficiency. The Newcomen engine required about 35 lb. of

coal per hour for each horsepower-hour capacity, while Watt's engine required but 8 lb. A modern turbine power plant requires less than 1 lb. per horsepower-hour.



Dennis Papin proposed (1690) an engine of cylinder and piston using vacuum

Newcomen built (1711) a practical steam engine. An attendant operated valves which alternately admitted steam and water to the cylinder

Watt separated (1769-84) the condenser from the cylinder; insulated the cylinder; made automatic valve mechanism; added flywheel and governor; made engine double acting; introduced cutoff using expansion of steam

Murdock invented (1784) the slide valve for admitting and exhausting steam; improved by Corliss 1849

FIG. 15.—Early steam engines. The steam engine was invented as a device for pumping water from mines. A third of a century later, the possibility of other applications became apparent.

Figure 15 illustrates the principle of the early steam engines.

Oliver Evans of Philadelphia contributed notably to the development of the steam engine in that he was one of the first to visualize the industrial possibilities of the

steam engine other than pumping water, and also he was probably the first to utilize high-pressure steam in an engine. He built engines to grind plaster, to saw marble, and to run a dredge.

Watt became associated with Matthew Boulton, a first-class businessman and owner of the ironworks at Soho, Birmingham. They built numerous engines according to Watt's plans, the first of which were actually set to work pumping water from a mine in the memorable year 1776. A long line of engineers have contributed improvements through the century and a half to make the steam engine an important converter of heat energy. The chief of these was George Corliss, an American engineer, whose drop cutoff increased the fuel economy and improved speed regulations.

Steam Turbine. The conception of the pressure or reaction when a fluid escapes from an opening is old—older than the steam engine, as exemplified in the reaction wheel built by Hero of Alexandria about the beginning of the Christian era. The reciprocating motion of the steam engine for most purposes must be converted into a rotary motion through a crank arm. A steam turbine uses the pressure of the steam against a series of blades on a rotor which forms a sort of complicated paddle wheel with a multitude of blades about as big as knife blades. While various attempts had been made previously, Charles A. Parsons, a highly educated engineer of England, invented the first practical turbine in 1884, when only 8 years out of college. He added the condenser in 1891. At the present time, the steam turbine, improved by C. G. Curtis, an American engineer, has nearly replaced the steam engine for the production of electric power and is being used extensively on ocean liners and elsewhere. The steam turbine may use the

reaction force of the steam or it may be designed to use the impulse force against the blades.

Internal-combustion Engines. In steam engines, the expansive gas (the steam) is heated outside the engine

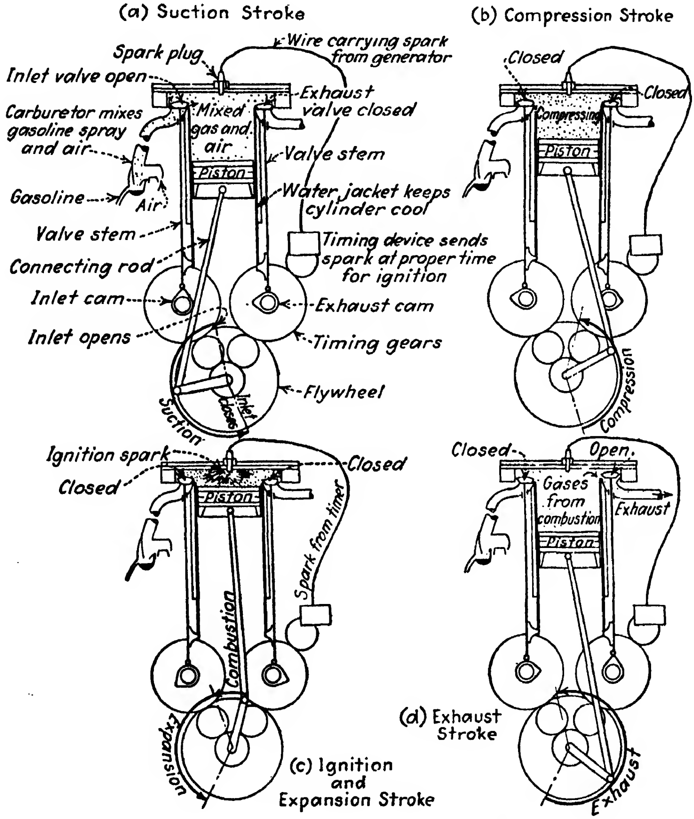


FIG. 16.—The Otto four-cycle internal-combustion engine. Invented first as a gas engine, but later used for gasoline and other fuels.

and introduced through a pipe with resulting loss of heat. The idea of generating the expansive gas by internal combustion, *i.e.*, generating it within the cylinder, had occurred to many inventors. Nicholas A. Otto, a German engineer, invented the four-stroke Otto-

cycle gas engine in 1878, which became universally used after the expiration of patent rights. About 1880, the Otto engine was modified to burn gasoline instead of gas, and since that time its use has become widespread. The four strokes, involving two revolutions, comprise (1) suction, (2) compression, (3) working, and (4) exhaust (see Fig. 16).

The Diesel oil engine was invented by Rudolph Diesel, a German engineer, in 1897. It is similar to a gasoline engine, except that it has higher compression, uses a heavier fuel oil, and does not have an electric ignition system since the heat of high compression ignites the slower burning fuel.

Heating. Heating of buildings from central heating plants, although practiced by the ancient Romans in a crude way, is largely a product of the nineteenth century. Stoves were introduced about the time Columbus discovered America. Heating by hot water is of great antiquity, and the Roman palaces were heated by warm air from subterranean chambers; but heating by warm air through conduits originated in England about 1816, and heating by steam about half a century later. In recent years, central heating has been extended to include heat service from a central plant to all buildings in a large area, and steam heat has been widely adopted for large buildings.

Air Conditioning. The desirability of introducing moisture into the air in artificially heated buildings in order to bring the humidity to that of naturally warm air early became apparent. From that simple procedure to the present development is a record of gradual improvement. Modern air conditioning, in which the air is heated or cooled as desired, filtered to remove dust, and moistened to yield the proper humidity

promises to be extensively applied. Theaters, hotels, and other public buildings, Pullman cars, and business offices are now furnished air to afford optimum bodily comfort.

Refrigeration. Until the beginning of the present century, refrigeration was furnished almost entirely by natural ice. Ice manufacture, accomplished by removing heat by means of a circulating brine, began about 1900 and the industry now amounts to 50 million tons annually. Not only in the manufacture of ice but in the refrigeration and storage of meats, fruits, and other perishable foods has refrigeration engineering become an important field. Artificial refrigeration is usually accomplished by compressing a gas by means of pumps and then allowing it to expand so that in expanding it will absorb heat from the thing to be cooled.

Energy Losses and Efficiencies. Stored-up energy, as in coal, is said to be *potential* energy, while energy involved in motion is called *kinetic* energy. Whenever energy is converted from one form to another, part of it is lost, and the conversion device is rated as E per cent efficient, where E is the proportion of energy received that is delivered.

Thus an engine that converts 25 per cent of the heat energy in the steam received into mechanical energy of the rotating parts is 25 per cent efficient; a boiler that delivers 75 per cent of the stored heat energy of the coal into heat energy of the steam is said to be 75 per cent efficient; a gasoline engine that delivers 24 per cent of the heat energy of the gasoline as useful work is rated as 24 per cent efficient.

The great advance in recent years in the use of energy has largely resulted from decreasing the losses or, in other words, increasing the efficiencies.

Power. It is related that Matthew Boulton, the early industrialist of England and partner of James Watt, the inventor of the first practical steam engine, was once engaged in conversation with George III, King of England.

The King asked, "In what business are you engaged, Mr. Boulton?"

"I am engaged, Your Majesty, in the production of a commodity which is the desire of kings."

"And what is that," eagerly asked the King.

"Power, Your Majesty," replied Boulton.

The industrialist was right, for the power that he conceived was waxing, while the power of kings was waning. The power used in industrial processes made modern England the great world power, brought wealth to her merchants and release from drudgery for her people—a power that the most benevolent of sovereigns might well have coveted.

Power and Horsepower. Power is the rate of doing work per second or per minute and hence depends upon speed as much as on the amount of work. A unit of measurement of power was an early necessity.

The horsepower as a unit of capacity to do work (energy) was adopted by the first manufacturers of steam engines, Boulton and Watt, as a sales device. Mine operators and others were accustomed to use horses on a treadmill or on a horsegear in operating pumps and other machinery and, therefore, had a conception of horsepower, so that the manufacturers had to interpret to the mine owners the capacity of engines in such terms as "This engine will do the work of 20 horses." Watt made experiments to test the capacity of a horse and found that 33,000 ft.-lb. of work per minute was a liberal allowance—in fact about one

and one-half times the actual performance—for a horse in sustained effort. He, therefore, adopted this as his unit of power, and it has never been changed. One horsepower is developed by a 1,500-lb. horse, which exerts a pull of one-tenth its weight while walking 2½ m.p.h.; or 1 hp. equals approximately the power developed by a stream of water 1 sq. ft. in cross section falling 10 ft. through a water wheel that is 90 per cent efficient, or it equals approximately the power consumed in 18 ordinary 40-watt residence lights. Figure 13 shows a common device for obtaining power from horses two centuries ago, which is still used by backward peoples.

CHAPTER IX

ELECTRICAL ENERGY

Source of Electrical Energy. Electrical energy is most commonly obtained by conversion from some other form of energy. Thus the energy of a waterfall through a turbine, or the stored energy of coal through a boiler and engine, is communicated as mechanical energy to a generator, which by rotating converts the mechanical energy into electrical energy. Electrical energy may also be generated by chemical action, as in batteries. In all such conversion processes, there is always some loss in the form of heat, which radiates into the air. Thus a generator which loses 10 per cent of the energy communicated to it and sends 90 per cent out on the line is said to be 90 per cent efficient. Electric energy can be stored in storage batteries somewhat as heat can be stored in hot water placed in a thermos bottle. Electricity should be considered, therefore, as a form of energy derived from other forms and convertible in turn into still other forms such as heat and light.

Pioneer Experimentation in Electrical Phenomena. Although observations on various electrical phenomena were made by the ancient Greeks and others, nothing definite was recorded until about the seventeenth and eighteenth centuries. The production of static electricity by rotating a glass disk against brushes and the storage of electricity in Leyden jars had grown up in the sixteenth and seventeenth centuries. About 1752, Benjamin Franklin, by means of a kite which carried a

conducting string, showed that lightning was the same as static electricity. He also put Leyden jars in parallel, thereby producing current strong enough to kill a fowl. It is related that, while conducting this experiment and endeavoring to compel the turkey to place its head in line with the spark, his hand came so near that he himself received the discharge and was knocked down. Upon getting up, he dryly remarked, "Well, I did not kill the turkey, but I knocked down a goose."

Luigi Galvani, an Italian physician, observed, while preparing some frog legs as a delicacy for his invalid wife, that when his steel knife struck the brass clamp with which he was holding them in salt water the frog legs twitched, causing him to infer that the contact of the different metals had an electric effect. Galvani's discovery, published in 1791 (with an incorrect theory of the phenomenon), led to Volta's experiments. Alessandro Volta, a professor of physics in Italy, discovered that a pile of silver and zinc disks with pieces of cloth saturated with salt water between produced an electric current, thereby inventing the electric battery. The unit of electric potential is called the *volt* in his honor. The electric battery was further developed in the century following.

In 1820, Hans Christian Oersted, a professor of physics in Denmark, accidentally discovered that an electric current from a battery flowing through a wire would deflect a compass needle, *i.e.*, cause magnetism. In the same year, André M. Ampère, a professor of mathematics at Paris, made similar experiments and discovered that, when a current from a battery flowed through a coil of wire, the coil took on the properties of a magnet. Thus it was found that *electricity could be made to produce magnetic force.* The converse, *i.e.*,

deriving electric energy from magnetism, remained undiscovered for another decade. The unit of current was named *ampere* in honor of this French experimenter.

Dynamo or Generator. The most important single contribution to electrical engineering was made by Faraday when he discovered in 1831 the converse of Ampere's proposition, *viz.*, that *magnetic force in conjunction with physical motion would produce electric current.*

Michael Faraday as a boy was apprenticed from age eight to twenty-one to a bookbinder and bookseller. In this connection he had opportunity to read many books, with the result that he developed an intense interest in science. He attended a series of lectures by Sir Humphry Davy, Professor of Chemistry and Director of the Laboratory of the Royal Institution at London, who was the foremost physicist and chemist in England at that time. Young Faraday longed to enter the field of science and so made application to Davy for an assistantship. In making application, he submitted a complete copy of his notes on Sir Humphry's lectures, systematically arranged. These made a favorable impression. The professor attempted to dissuade him by telling him that science is an exacting taskmaster, requiring extraordinary diligence and offering small monetary rewards. Young Faraday felt that his life's happiness lay in the pursuit of science. He was finally (1813) given a job in the laboratory at 25 s. ($6) per week caring for the apparatus. Faraday's capacity is shown by the fact that just 20 years later, at the retirement of Sir Humphry, he succeeded that distinguished scientist as professor and director of the laboratory.

In the eighteenth year of his service in the laboratory (1831), Faraday made the great discoveries (1) that an

electric current was produced in a coil of wire when drawn past a magnet, (2) that, when a loop of wire was rotated between the poles of a permanent magnet, an electric current was generated in the wire, and (3) that, when a copper disk was rotated with its edge between the prongs of a permanent magnet, an electric current was generated (see Fig. 17).

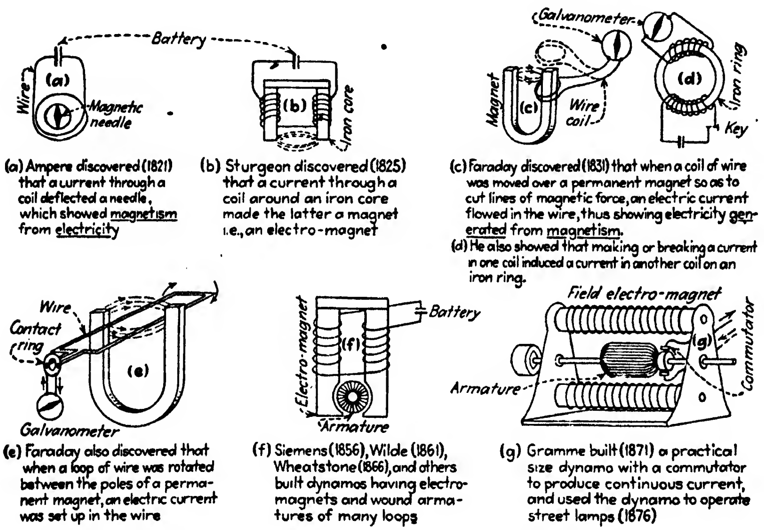


FIG. 17.—Early stages of the electric generator. The generation of electric energy from motion and magnetism was one of the world's greatest inventions.

Thus Faraday discovered how to produce *electric current* from magnetism by moving a wire so that *it cut the lines of magnetic force.* This is the principle involved in the electric dynamo or generator, in which, by winding, many loops are made to cut the lines of force at each revolution.

When Mr. Gladstone, the prime minister, was shown the invention, he, a stranger in the realm of science, did not grasp its significance and inquired of what use

it might be. Faraday, with typical Celtic humor and realizing the chief interest of the distinguished statesman to be fiscal, replied, "Some day the government may be able to tax it." The quality of his prophecy is indicated by the fact that the electric industry, which had just been born in Faraday's discovery and lay in its helpless infancy before them, has grown to such proportions that it pays a large bulk of the taxes of all civilized nations.

Faraday a little later discovered that, if two coils are wrapped about an iron bar and a current is made and broken through one coil, a current is induced in the other coil. This is really the principle of the transformer, which was to be so widely used later in connection with alternating currents.

The Practical Generator. Faraday, an experimentalist, left the dynamo in the experimental stage, so that it fell to practical engineers to make his wonderful discovery useful in the world of affairs. Although Wheatstone and others made some advances, the dynamo did not take on practical proportions until Z. T. Gramme, a Belgian engineer, in 1870, built a commercial size dynamo that could operate arc lights. Up to that time, there had been no commercial use for electric energy and hence no incentive for its generation. With the development of arc lights for street lighting (1876), electric generation was given an impetus.

When some workmen were setting up some Gramme dynamos at the Vienna exposition in 1873, they accidentally connected one to the wires from a dynamo already in motion. To the astonishment of all, the second began to rotate rapidly. Gramme, when his attention was called to the incident, recognized the significance of the discovery, *viz.*, that a generator

could be run as a motor by applying current to it. The invention of the electric motor made possible the use of electric power in factories and elsewhere.

Coordinate with the experimental and practical discoveries, the mathematical analyses by Clerk Maxwell and William Thomson in England and H. R. Hertz in Germany were required to bring electrical engineering to the status of exact laws that could be used in the design of electric equipment.

As soon as electric lighting and the development of the electric motor furnished a commercial use for electric energy, advances in the technique and the economy of producing electric power were made by leaps and bounds.

The extensive use of alternating current in place of direct current has come about largely in the present century as the result of inventions by Nikola Tesla, B. G. Lamme, and others, and the scientific investigations of such men as C. P. Steinmetz and J. J. Thomson.

Power Transmission. Power may be transmitted by a variety of means, such as shafts, belts, rope drives, air, water, and by electric current, but electric current is probably the most efficient method of transmitting power.

Until about the beginning of the present century, electric energy was generated at relatively low voltages, 220 volts or less. The distance to which electric energy will flow through wires is dependent upon the voltage or potential, just as the distance that water will flow through pipes is dependent upon the head at the source. Therefore, the early history of transmission related to short distances, as within a single city.

In recent years, higher voltages, up to 220,000, have been used in transmission, which permit economic

transmission to greater distances, 250 to 300 miles. These greater distances of transmission have caused electric power to be generated at large central stations and distributed to interconnected cities, thereby eliminating uneconomical small plants. Transmission at the higher voltages has been made possible by the invention of better insulators and better lightning protection.

Central Stations. Advances in building more powerful steam turbines and more efficient boilers and in electric-power transmission have favored the building of large central power stations which have permitted notable economy in the production of electric power. Central stations are commonly located where coal can cheaply be shipped in and where a natural body of water is available for steam condensation. With modern boiler equipment the amount of coal used to furnish a kilowatt-hour of electric energy has been reduced to one-fifth of that required a few years ago. The first real central station was the Pearl Street Station, New York, designed by Edison (1882). Its capacity was 10,000 lights, or about 1,000 hp. The early stations were 5,000 to 10,000 kw. capacity, while a typical modern, large one is the 208,000-kw. plant at State Line Station near Chicago, where the largest single unit is 76,000 kw. capacity. This plant will ultimately be extended to 1,000,000 hp.

Electrical Units. Most electrical units have been named in honor of men who have contributed notably, through either scientific discovery or invention, to the development of electrical engineering. Thus the unit of current is the ampere, the unit of resistance in a conductor is the ohm (Georg S. Ohm of Cologne, who formulated the law that the current flowing varies with the voltage and inversely with the resistance), and the unit of power, the watt (after the inventor of

the steam engine). The watt is the amount of power developed by 1 amp. of current under 1 volt flowing through a resistance of 1 ohm, or about one-fortieth the power used by the ordinary residence light. It represents 0.737 ft.-lb. per second, or about the amount of power developed by a small bird in flight. It is too small for a practical unit; hence, 1,000 watts, or 1 kw., is commonly used. A kilowatt equals about 1⅓ hp.

Electrical units, like all other units of measurement in their initial stages of development, were ill defined. The Daniell cell afforded a natural unit of potential, and the volt adopted later was given a value nearly equal to the potential of that cell. The ohm was at first the resistance of a column of mercury a meter long and 1 sq. mm. in cross section, but in later refinement and in adjusting to other systems of units the standard mercury column was taken at 106.3 cm. long at 0°C. A copper wire 1,000 ft. long and 0.1 in. in diameter has practically 1 ohm resistance. Similarly the ampere is standardized as the amount of electricity flowing per second when the current will deposit 0.00118 gram of silver per second from a standard solution. All of these units have been refined through the action of international congresses, most of the present units having been adopted in 1893.

Electric Lighting. The chief use of electric energy at present is electric lighting. Sir Humphry Davy in 1802 heated a platinum wire by an electric current from a battery until it became white hot and gave off light. He also discovered the brilliant light when current passes between two carbons, the essential principle of the arc light. The arc light was used for street lighting in France about 1876, although its practical utility later was developed largely by Charles Brush, a Cleve-

land engineer. Grove (1840), De Moleyns (1841), Starr (1845), Shepard (1850), Farmer (1859), and Crookes (1875) made advances toward an incandescent light. Thomas A. Edison began in 1877 to experiment with various filaments in a vacuum and finally succeeded (1879) in making a successful carbon filament, thereby inventing a practical electric light.

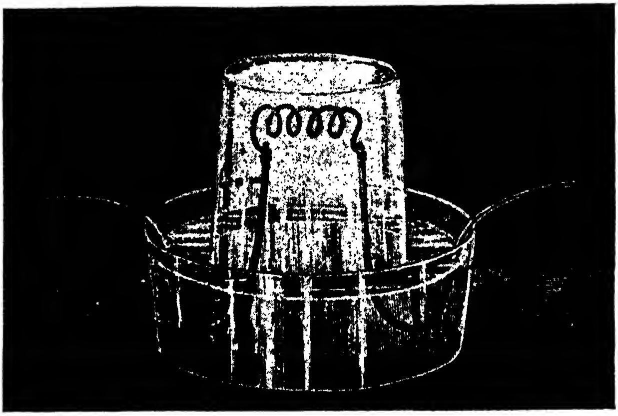


FIG. 18.—Grove's incandescent lamp. In 1840, Prof. W. R. Grove of London lighted a room experimentally with such platinum coil lamps. Much experimentation made incandescent lamps practical a half century later.

Edison's first light had a filament of carbonized sewing thread, which he had made by heating in a vacuum, and after many trials had succeeded in inclosing in a glass-bulb vacuum. When in October, 1879, he first turned the current on his light, cautiously by means of resistance at first and then full force, probably not even the inventor had expected the carbon to last more than a few minutes. To the surprise of all, it gave a brilliant light for more than two hours. Subsequent experiments showed filaments made of bristol board most satisfactory, and the announcement of the great invention was made December 21, 1879.

Edison not only made a practical lamp but devised the system of multiple or parallel connecting of lights in which one light might burn out without affecting the others, as had been the case in the series arrangement used up to that time. This invention made the incandescent light practical for home lighting. Because Edison's experimental generator gave good lighting results at 110 volts, he adopted that potential for his experiments, and as a consequence most electrical power is generated at that voltage or in even multiples.

The carbon filament with gradual improvement and modifications was standard for a quarter century when Alexander Just and Franz Hanaman, two chemists of Vienna, invented the tungsten light and the General Electric Company purchased their patents. Within the past decade, Dr. W. D. Coolidge and Dr. Irving Langmuir of the General Electric Company have greatly improved the efficiency and the procedure in the manufacture of the incandescent light. Even high-grade modern filament electric lights convert 90 to 95 per cent of the electric energy received into heat and only 5 to 10 per cent into light, so that they can be said to be only 5 to 10 per cent efficient. Some modern developments indicate that this performance may be greatly improved. Powerful lights of various sorts are made for flood and beacon lighting.

Electronics. Chemistry and physics at the turn of the century assumed the atom to be the ultimate elementary particle in the constitution of matter, but later researches have shown the atom to be a system of particles. This system consists of a nucleus at the center carrying a positive charge of electricity and containing nearly all the atomic weight, and a group of electrons (the number depends on the substance) carry-

ing constant negative charges of electricity equal in total to the positive charge on the nucleus, and revolving about the nucleus. Furthermore, within the nucleus there is a cluster of heavy protons with positive charge and light neutrons spinning and revolving in orbits. The spinning and revolving of these particles represent energy, the total of which in the mass of atoms owing to the high velocities is tremendous, capable of supplying the world with power for all time. The subatomic energy of a few pounds of matter, if available, would furnish electricity to a large city for a year. The electrons frequently shift their orbits about the nucleus, and they can be made to stream off through space or in a conductor as electric impulses and electric current. The science of the behavior of electrons within the atom and outside, called electronics, is playing an important part in modern engineering development. It is the basis of radio, television, radar, the photoelectric cell, and the many electrical instruments used for aiding aviation, industrial controls, and operating commercial devices. The development of electronics represents the work of so many physicists that no brief historical statement is possible. The theory was postulated by Hendrik Lorentz, a Dutch physicist, who about 1895 extended the field equations of Maxwell to the electron concept. The theory has been confirmed and amplified by many investigators since that time.

Electrical Waves. Electrical impulses with respect to their physical composition are not well understood, but their behavior has been observed and reduced to established laws. They have the properties of waves in that they vary from maximum to minimum in a rhythm of definite frequencies. Hence, they are conceived as "waves," and analyses based on that conception have

done much to advance electrical engineering in recent years. They are considered as having a "wave length," *i. e.*, distance from one maximum to the next along the line of travel, and to have a frequency, or the number of impulses occurring per second. The wave length ranges from about 5 million meters (3,000 miles) in 60-cycle power waves to 1 trillionth of a millimeter for gamma rays and much shorter for cosmic rays. The corresponding range of frequencies is from about 60 to 300 billion billion per second. The scale of typical wave lengths from longest to shortest would be somewhat as follows:[1]

Power waves, 60 cycle	5,000,000 m.
Radio	5 to 30,000 m.
Regular broadcast	180 to 540 m.
Short wave	10 to 180 m.
Heat waves	0.03 cm.
Red light	0.000,08 cm.
Violet light	0.000,04 cm.
Ultraviolet	0.000,03 cm.
X ray	0.000,000,001 cm.
Gamma rays	0.000,000,000,1 cm.

Cosmic rays, about 1/100 as long as gamma rays, have not been used in engineering processes. The shorter the waves, the greater their penetrating power. Visible light rays will penetrate glass with little diminution, as is well known; ultraviolet rays will penetrate quartz; X rays will penetrate flesh and show the bone condition beneath; gamma rays will penetrate iron or steel and are used by metallurgists to study the interior structure of metals; cosmic rays have been found to penetrate a considerable thickness of lead. Since all electric waves travel at the same velocity, *viz.*, 300 million meters per second, that velocity divided by the wave-length gives the frequency and vice versa. Electric waves will doubtless be even more important in engineering in the future.

[1] J. O. PERRINE, *The Sci. Monthly*, January, 1944.

CHAPTER X

TRANSPORTATION

Introduction. Perhaps no other factor has more influenced the economic and social development of the human race than has transportation. The speed, reliability, cost, and capacity of the transportation facilities have largely determined the nature of political organization and the range of trade. Although roads represented an aspect of engineering art, it was not until transportation left the age of beast of burden by land and that of the galley slave and square sails by sea that transportation really became a matter of engineering.

Ancient Roads. The roads of the ancient peoples before Imperial Rome were rather crude affairs. Military transport was not so urgent, water transport was available for commerce, and, in the semiarid regions around the Mediterranean, earth roads served the needs of camel caravans and of local intercourse. However, Herodotus (450 B.C.) reports a tradition of his day that the king of Egypt had built a road of great thickness for transporting the stones for the Pyramids (3000 B.C.).

With military and commercial Rome there came a need for improved transportation. Her armies must be moved quickly and reliably and her rich merchants were disposed to exploit the markets of the more backward interior of Europe. Consequently, Roman roads traversed not only Italy but all of Central Europe. Embankments were built across swamps and the roadway drained; deep cuts and tunnels avoided the summits of hills.

The road itself in its best form is represented by the Appian Way. Built about 312 B.C. and extending 140 miles south to Capua, it connected Rome with the second largest center of population and commerce in Italy at that time. This road consisted of large stones about 1 ft. thick laid in one or two layers at the bottom of a deep trench, gravel with clay or cement to a depth of about 2 ft., and, on top, a pavement of hard flat stones about 1 ft. thick carefully laid. The road was, therefore, 4 to 6 ft. thick. The Appian Way was about 14 ft. wide, although most roads were only about half this width. The mountain roads of the Alps were only about 5 ft. wide, although a few were more than 20 ft. wide. The total road system extended some 50,000 miles and was marked with regular mile posts.

Little improvement was made in the art of road building until the beginning of the nineteenth century. In fact, the roads of the intervening centuries were vastly inferior to the ancient highways.

About the beginning of the last century, John Loudon Macadam, a Scottish engineer, discovered that crushed rock would bind together to spread a concentrated load over sufficient area of earth to secure adequate support. Macadam roads were built in England and America quite generally until the advent of the automobile in the present century, whose rubber tires and wheel traction caused their rapid destruction. To serve automotive vehicle traffic, more resistant surfaces have been built in the last half century of concrete, brick, and bituminous mixtures.

Evolution of the Vehicle. The evolution of the simple wheeled cart as shown in Fig. 19 is typical of the development of engineering devices generally, even of the most complicated sort. Almost invariably they have grown

gradually from an elemental form to the matured design. The earliest transportation was by carrying and by dragging, heavy objects being dragged on a sledge. In due course, round logs put under the sledge as rollers were found to diminish the necessary pull. Then some one discovered that the rollers might be made stationary with great convenience, and, centuries after, fixed rollers were improved by cutting away the mid-portion to the

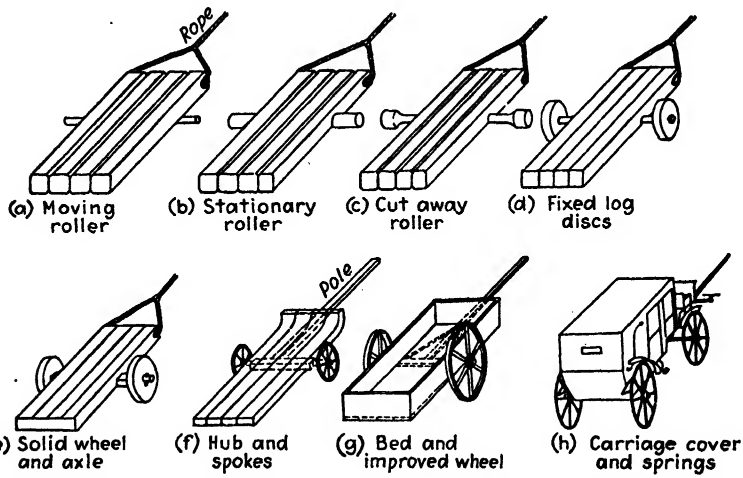


FIG. 19.—Evolution of the vehicle. Probable advances at about 1,000-year intervals. The slow progress of mechanical arts in early history is illustrated by the development of the vehicle.

size of an axle and leaving the large diameter rollers at the ends projecting beyond the sledge body. Following this improvement, rollers consisting of transverse slices of huge logs were attached to the ends of the axle, thereby rendering the rollers more effective. The next step was to bore these large solid rollers to allow them to turn on a fixed axle. Shafts or a pole were then fastened to the axle. The Assyrians and the Egyptians devised the wheel with spokes (four to eight) of wood at first (perhaps 1000 B.C.) and later bound with iron.

The English developed vehicles of superior quality as evidenced by the fact that Cicero, the Roman politician, wrote a friend in Britain asking him to send an English chariot and remarking on its superiority.

While four wheels were sometimes used by the ancients, the vehicle regularly took the form of the cart or chariot until the Middle Ages, when the four-wheel carriage with swinging front axle was developed about the sixteenth century.

Railroads. Wheelways were used by the ancients, and rails of timber with strips of iron for the tread were used perhaps two hundred years before the locomotive was invented. Rails of this sort were in use at Newcastle-on-Tyne where Stephenson later first used a steam engine for haulage, nearly one hundred fifty years before the latter event. The first types of locomotives were built to run on the street; and putting the locomotive on rails was merely an adaptation after it had been proved that iron wheels on iron rails would develop through friction enough traction to pull a train of wagons.

The flat iron strips were fastened to the longitudinal timbers by means of screws. These strips were then turned on edge to increase their durability, and the widening of the top into a head and of the bottom into a flange rapidly followed.

At first, the rails were laid on stone sleepers, but in laying one of the first steam railroads in America (the Baltimore and Ohio) when the supply of stone sleepers ran short, wooden ties were used as temporary expedient. This type of construction, having been found superior to the original, was continued, and up to the present no better has been discovered.

Rails were at first of cast iron, then of rolled iron; but since cheap steel became available at the middle of the

nineteenth century, they have been of steel. At first, the rails weighed 40 or 50 lb. per yard, but now very heavy traffic lines use 112- to 150-lb. rails.

The flange on the wheel (invented by William Jessop in 1788) has been a most remarkably efficient and convenient device. It has not only guided the trucks over the rail but has made switching easily effected. The early switch was of the "stub" variety, consisting of the switch rail laid beside the running rail at a joint in such a way that it could be sprung over into line and the running rail sprung out of line. The modern switch points have been developed within the last half century.

The gage of railroad track (distance inside-to-inside of rail heads, 4 ft. 8½ in.) was obtained as the average of vehicles operating over the railways of England at the close of the eighteenth century. Although various gages have been tried varying from 3 to 6 ft., the old standard has been almost universally adopted as the most satisfactory.

The railways in America were built originally chiefly as small local lines and the great systems of today were formed by joining these together. Some of the problems of today are involved in improving these lines so that they can carry the traffic more economically. These improvements consist of reducing the grades, curvature, and distance. Grades are rated in percentage, meaning the number of feet rise in 100 ft. along the track. Thus, a 1.2 per cent grade means 1.2 ft. rise in 100 ft. Curves are arcs of circles.

About 75 per cent or more of the revenue of railroads is obtained from freight traffic, about 15 per cent from passenger traffic, and the rest from mail, express, and miscellaneous. On the earliest railways, most of the revenue came from passenger travel, the freight consisting of

small parcels. The engine man collected the fares and the fireman handled the baggage and freight. At

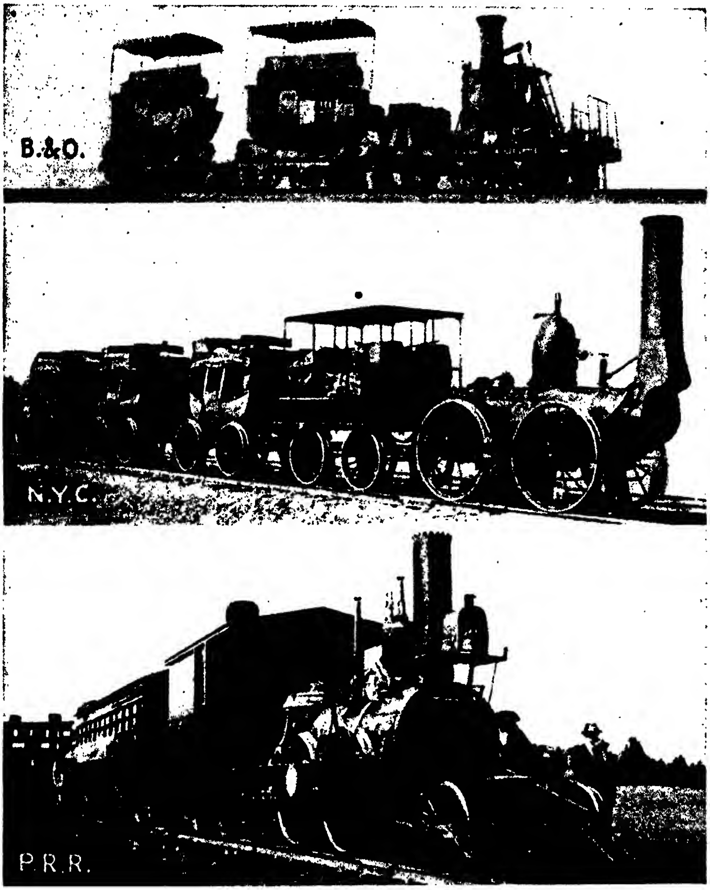


FIG. 20.—Early trains. Much individuality characterized the rolling stock of the first railroads.

present, there are 240,000 miles of railways in the United States, or about one-third of the mileage of the world.

About 50 per cent of operating expenses go for running the trains, 18 per cent for upkeep of roadway, 24 per cent

for upkeep of equipment, and the balance for advertising and miscellaneous.

Figure 20 shows the first trains of the Pennsylvania (*a*), the Baltimore and Ohio (*b*), and the New York Central (*c*) railroads, respectively.

Automobiles have so taken passenger travel and freight haulage that railway operations have been seriously affected. A problem of the future is adjusting the various agencies of transportation to a proper relationship.

Locomotives.—The locomotive followed shortly after the invention of the steam engine. A young man, William Murdoch, applied to Boulton and Watt, the engine makers, for a job. Being a bit nervous while talking to the famous manufacturer, he dropped his hat, the impact of which on the floor attracted Mr. Boulton's attention. On examination, Boulton was surprised to find it made of wood turned on a lathe. He readily gave a young man of such ingenuity a job at 15 s. per week, and the young man developed rapidly.

Young Murdoch found time on the side to construct a steam locomotive about 14 in. high and 20 in. long. In it, he invented and used the D-slide valve and other ingenious details. It was capable of drawing a small wagon around Murdoch's room, and one night be tried it out on the sidewalk, much to the alarm of a clergyman, who mistook it for the Evil One.

Richard Trevithick, an apprentice of Murdoch's, probably built the first practical locomotive. In 1802, Trevithick built one at Coalbrookdale and in 1804 one for the Pen-y-darren tramroad. The latter had a cylinder 8¼ in. in diameter and 4½-in. stroke. A bellows was used for blowing the fire. Trevithick built

another locomotive in 1808 which operated at an exposition at 12 m.p.h.

In 1802, Oliver Evans of Philadelphia built a locomotive that would run on the streets. Timothy Hackworth, William Hedley, and Jonathan Foster built locomotives at Wylam during the first 15 years of the century.

George Stephenson, son of a fireman of the colliery engines at Wylam, however, is generally known as the originator of the locomotive, because his locomotives proved to be the most successful. He became a fireman at Dewley and, later, engineman at Water-row on the Tyne River. He was unable to read or write but, being told that certain books described Boulton and Watt's engines, he set out to learn under a tutor. He never missed an opportunity to study either books or practical engines. In 1814, he completed his first locomotive which was found to be more expensive than horses in operation. He then thought of the chimney blast and exhaust which would keep the fires burning. Presto! the locomotive became a success. Stephenson built several for coal-mine roads and exerted every effort to have them more widely adopted.

In 1821, the Stockton and Darlington Railroad was authorized by Parliament, with the type of motive power—horses, stationary engines with drums, sails, or locomotives—undetermined. Stephenson convinced the directors that they should use his locomotive, and he was appointed chief engineer, to make the surveys, construct the road, and furnish three locomotives on trial. The road was opened September 27, 1825, and at the signal the locomotive started off with an "immense train of carriages" and attained the speed of 12 m.p.h. Figure

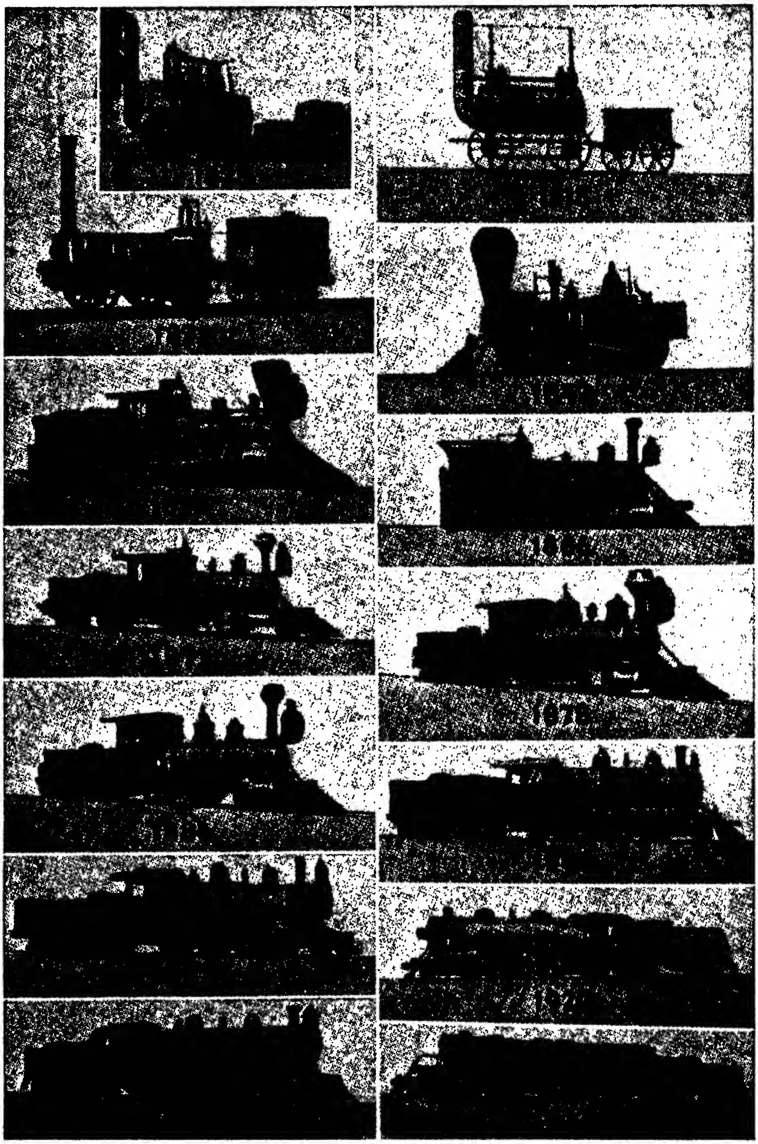


FIG. 21.—Development of the steam locomotive. The growth of a century. Passenger-train locomotives on the left and freight on the right.

21 shows the evolution of the locomotive through types at successive decades.

In the selection of locomotives for the Liverpool and Manchester Railroad, Stephenson's *Rocket* won the award over four competitors, although the *Novelty* by Braithwaite and Ericsson demonstrated much superiority in operation, losing the award because of a defective flue. (Ericsson later came to America and is best known as the builder of the *Monitor* warship.) America followed England immediately in railroad building, as did other European countries, Austria and France in 1828, and the United States in 1829.

On August 8, 1829, a trial of a steam locomotive was made near Honesdale, Pa., on track later owned by the Delaware and Hudson Railroad which was the first steam-railway operation in America. (This track was abandoned in 1931.) Horatio Allen, a civil engineer who had built the line, ran the locomotive. The first practical railroad in America was from Philadelphia to Morristown opened in 1832, although the South Charleston Railroad (South Carolina) had been opened a year previous.

On July 4, 1828, the venerable Charles Carroll of Carrollton, the last surviving signer of the Declaration of Independence, turned the first sod for the construction of the Baltimore and Ohio Railroad. Envisioning the future of railroad transportation, he remarked that he considered this symbolic beginning of railroad construction to be the most important act of his life, not second even to the Signing of the Declaration.

A spectacular race occurred in 1830 over the first 13 miles of the Baltimore and Ohio Railroad out of Baltimore between a locomotive built and run by Peter Cooper and one of the famous stagecoaches drawn by a

prize horse on the parallel track. At first the horse had the better of the race but soon the race was neck and neck and then the locomotive passed the coach. However, the belt which turned the fan to blow the fire in the boiler broke, the fire died down, the engine began to slacken, the horse galloped past and won the race into town. Nevertheless, the trial revealed the ultimate possible superiority of the locomotive.

Navigation. The Egyptians and Phoenicians as early as 3000 B.C. had boats of considerable size propelled by rowing. Noah's ark, according to the Biblical account, was about 525 ft. long. Greece and Rome developed ships for both commerce and war propelled by oars in the hands of galley slaves. Sails were constructed by the Egyptians of mats and palm leaves, later of linen, and their use was extended by the Romans. However, the sailing equipment was of the simple square type permitting them to sail only with the wind. Tacking and sailing against the wind and holding direction regardless of shifting wind were evolved some time before Columbus discovered America and doubtless, along with the compass, had much influence in the maritime activity that included that epochal voyage.

As in the case of the railroads, men were not long in adapting the steam engine to propulsion of watercraft, and numerous inventors of steamboats sprang up. John Fitch of Philadelphia built a steamboat in 1788 with paddles at the sides, which operated regularly between Philadelphia and Trenton in 1790. The next practical steamboat was the *Charlotte Dundas* built by William Symington in Scotland in 1802. John Stevens of Hoboken built and operated one in 1804. Robert Fulton's *Clermont*, which began regular operation between New York and Albany in 1807, is commonly

considered the first successful steamboat, chiefly because it established itself as a regular commercial carrier. The first steamboat to cross the Atlantic was the *Savannah*, an American vessel, which made the trip, partly by sail and partly by steam, in 1819. The *Great Western* in 1838 was the first to establish regular transoceanic service.

John Ericsson invented the screw propeller, which was first used in the *U.S.S. Phoenix* in 1844 and which soon came into universal use. Steam turbines and oil-burning boilers have replaced the old steam engine within the present century. Wireless and radio have removed most of the hazards of ocean shipping and the newer vessels are held on their course automatically by means of the gyroscope operating the rudder. Modern vessels steam at 25 to 30 m.p.h., as against the *Clermont's* 6.

Waterways. The interior civilizations of medieval countries largely depended upon the navigation of rivers and of canals. The Nile, the Thames, the Seine, and the Rhine permitted the growth of large interior cities. In the United States, practically all large inland cities are on navigable water. Even though their later growth has been controlled by land transportation, their location and early lead in growth came from waterway carriage. In the first three decades of the eighteenth century canals were built extensively, many of which, such as the Erie (opened 1825 between Lake Erie and Hudson River), carried heavy traffic. With the rise of the railroads, river and canal traffic all but disappeared. The original Erie Canal, 4 ft. deep and 40 ft. wide, was enlarged in 1905–1918 to 12 ft. deep and about 75 ft. wide and is now called the New York Barge Canal. The Panama Canal, built 1904–1913,

conveying the largest vessels between oceans, is the most notable artificial waterway. In recent years, a movement to connect the Great Lakes and the Mississippi system into an inland-waterway scheme has been undertaken as a part of the national transportation strategy, together with coastal canals which would permit coastwise shipping to keep in sheltered waters. Closely related to this Mississippi system is the proposed Great Lakes-St. Lawrence waterway, which as planned at present will accommodate vessels of about 26-ft. draft, which would include most of the ocean ships.

Electric Traction. The development of the electric motor in the latter part of the nineteenth century caused many inventors to consider its use in operating vehicles. C. J. Van Depoele, a Belgian mechanic, devised the trolley pole with a grooved pulley at the end for contact—humorously called the "witch's broomstick" by the poet Holmes. Frank J. Sprague, an energetic American engineer completed the first trolley-driven car on the old mule-operated street railway of Richmond, Va., in 1888, causing a wondering negro to exclaim, "First dey freed de darky, and now dey freed de mule!" For a quarter of a century electric cars were widely used in all cities, when the advent of the automotive vehicle caused the decline in all smaller cities. Elevated and subway electric trains still carry the bulk of the traffic in large cities.

Steam railroads are being electrified wherever the traffic is sufficiently heavy to warrant the heavy investment in power house and transmission system. An enthusiastic young electric engineer once predicted in the hearing of Andrew Carnegie that in 10 years there would be no steam locomotives. With typical canniness, Mr. Carnegie commented, "Well, it's fine

for young men to prophesy, but they shouldn't set dates."

The economy of electric traction is limited to conditions of dense traffic. Gasoline and Diesel locomotives are being widely introduced for light traffic, but for moderate traffic the steam locomotive is still the economic motive power.

Automobiles. While numerous steam vehicles were invented as forerunners of the locomotive, the first gasoline automobiles were built by Panhard and Levassor in France (1891) and by Haynes and Duryea in America (1892–1894). However, Carl Benz of Mannheim, Germany, had built (1885) a vehicle propelled by an internal-combustion engine, and Gottlieb Daimler had invented the ignition which gave high speed to the engine. The early types followed the general lines of a carriage, but for higher speeds it was necessary to make the center of gravity near the ground—hence the low wheels. The automobile consists of three essential parts: the chassis, the body, and the power plant. Great improvements are being made with every new model in the design of each of these elements. There are now approximately 26 million passenger cars and 5 million trucks in the United States, which use nearly 23 billion gallons of gasoline annually. While the four-wheeled vehicle required thousands of years, and the locomotive a century, the automobile required but three decades to attain a high degree of perfection.

Aviation. Although the development of balloons began soon after the discovery of hydrogen in 1776, and two men drifted across the English Channel in 1785, modern aviation is of the present century. The dirigible airship, essentially a balloon with propulsion, was evolved chiefly in America and Germany, while the origin of the

airplane is almost entirely American. Otto Lilienthal in Germany, P. L. Pilcher in England, Clément Ader in France, S. P. Langley, and Octave Chanute in the

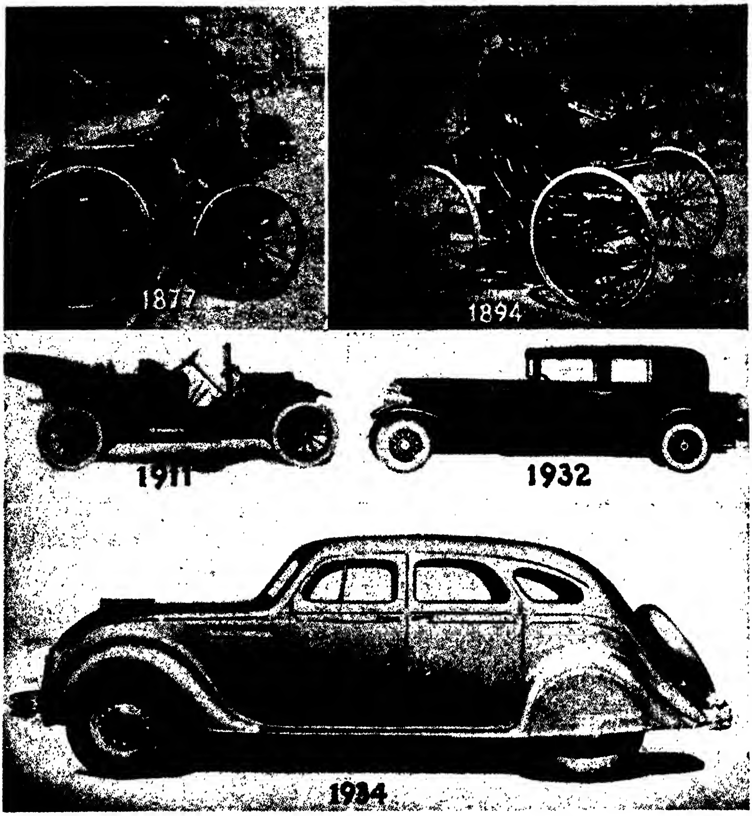


FIG. 22.—Development of the automobile. The rapid development of the automobile and of other recent innovations has resulted because of the availability of an advanced technical science. Compare with Figs. 21 and 19.

United States were pioneers in experimenting in the laws of flight.

The real originators of practical flight were the brothers Orville and Wilbur Wright. Their experiments began with a glider at Kitty Hawk, N. C., in 1900, and in

December, 1903, they made flights with a motor driving a glider which lasted 12 to 59 sec.

Their invention derived from three sources: (1) a toy airplane with two propellers turned in opposite directions by rubber bands, given them as boys by their father, which they improved and reproduced in numbers; (2) a favorite hobby of kiteflying for which they became locally famous; and (3) their mechanical skill in bicycle repairs in which as young men they engaged as a business. They went to Kitty Hawk for modest seclusion and because the deep sand dunes would minimize discomforts from anticipated falls. From the crude cloth-covered plane weighing 750 lb. including the pilot, which took to the air that day to the modern stratoliner is the marvelous development of four decades. Figure 23 illustrates that achievement. The prone position of the pilot (Orville Wright) on the lower wing of the pioneer plane (*a*) is in marked contrast to the luxurious accommodations of the stratocruiser in (*e*). Brother Wilbur running at the right had held the wing at the takeoff.

A Boeing transport plane (*c*) flew from Seattle to Washington, D.C., in 6 hr. 4 min., average speed 383 m.p.h., carrying 20,000 lb. of pay load. Such a plane is practical only for long flights; small planes flying at 200 m.p.h. can service stops 50 to 60 miles apart; inexpensive planes for private use are being developed. Huge glider planes with wings 105 ft. tip to tip carry 6 tons when towed. They have small engines and propellers to assist in the takeoff.

The costs of airway transportation are high and increase with the speed; hence the cargoes are economically limited to valuable light articles. Thus far, airports have been furnished at public expense and are not included in rate calculations. Ultimately, railway,

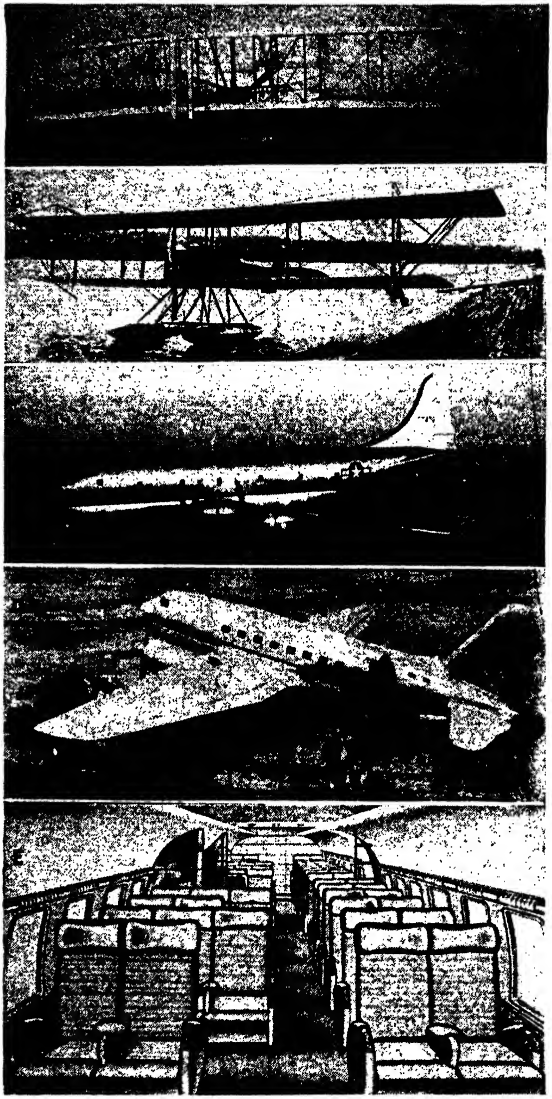


FIG. 23.—Development of the airplane. (*a*) First flight at Kitty Hawk (1903); (*b*) Curtiss hydroplane (1916); (*c*) Boeing transport plane in flight (1944); (*d*) Curtiss passenger transport unloading; (*d*) interior of Boeing stratoliner. (*Courtesy of the Curtiss-Wright Corporation and the Boeing Airplane Company.*)

highway, and airway transport will be coordinated on an economic basis.

Pipe-line Transportation. Pipe lines for the transportation of petroleum and gas as well as water have been extensively built. At present there are about 321,000 miles of pipe lines in the United States, which link oil fields with refineries, water terminals, and distribution centers. In 1940, they carried nearly a billion barrels of oil, including about 7 per cent of shipments from the mid-continent fields to the eastern seaboard. Pipes are about 12 to 24 in. in diameter and are laid in 40-ft. sections welded together. Pipe lines are operated much like a railroad, with trunk lines and feeders, storage centers, switching system, and dispatchers. Gravity moves the oil at times, but usually pumping engines about 30 to 40 miles apart are used. The power necessary is determined by the capacity and the terrain, for the lines go over hills and under rivers. Pipe lines have become an important engineering specialty.

Coordination of Transportation Agencies. Railways, highways, waterways, pipeways, and airways afford the agencies of transportation, each having its peculiar characteristics of speed, cost, capacity, convenience, safety, and reliability. The proper coordination of these agencies to promote economy and social benefit constitutes an intricate but urgent engineering problem. A comparison of relative economies to be complete must comprise all costs including any governmental subsidies. Transportation is an essential of national life as well as a private convenience; hence agencies of transportation are affected with public interest and are subject to public regulation. They are called common carriers and like public utilities are under special laws.

CHAPTER XI

COMMUNICATION

Introduction. Perhaps few achievements of the engineer have had more marked influence than modern communication. The ancients were dependent upon the foot courier or upon fire signals flashed from hilltop to hilltop. The exploit of the runner who ran approximately 26 miles to announce the victory of the Battle at Marathon (no timepieces; hence, time unknown) stands as the acme of achievement in ancient communication, and a feat which has constituted a challenge to fleet-footed athletes ever since.

The Telegraph. Experiments by Francis Ronalds in England, who transmitted signals 8 miles over a wire by an electroscope (1840), by Fothergill Cooke, and by Charles Wheatstone forecast the telegraph. Cooke and Wheatstone communicated signals by means of electric currents in 1837. Samuel F. B. Morse, an artist of New York, became interested in such signaling and invented the Morse code for transmitting the letters of the alphabet and thus made the telegraph practical.

The story of Morse's invention is a colorful scene in the drama of engineering development. Morse inherited a scientific and inventive bent as well as his artistic talent. He entered Yale College at age thirteen and studied, among other subjects, chemistry and physics for three years under distinguished teachers of science. After college, he wavered between the career of an inventor and the life of an artist, in the meantime com-

pleting several minor inventions. Success in certain painting trials turned him to art. He studied under Benjamin West and the foremost artists of Europe. When returning aboardship, he fell in company with Dr. Charles T. Jackson of Boston, a distinguished scientist, who related his interesting experiences while in Paris attending lectures on electromagnetism by Professor Ampère. Dr. Jackson remarked that electricity passed instantaneously over any known length of wire. Morse responded, "I see no reason why intelligence may not be immediately transmitted by this means." Thereafter, he was absorbed in the achievement of that result, and his experimentation is an example of heroic persistence.

The final chapter of Morse's struggle to secure recognition and assistance affords a gripping narrative. Morse, a sensitive artist and deeply religious man, felt "that God had created the great forces of nature . . . as expressions of good will to man, to do him good, and that every one of God's great forces could be used for man's welfare." He had spent all of his earnings in developing his invention and at times had not enough left for adequate food. He applied to Congress for aid and sat in the gallery during the debate of the bill. It passed the House. Day after day wore on, and the bill was not reached in the Senate. The last hours of the session were drawing near. A senator advised Morse to go home and think no more of it.

With barely enough money left to buy a ticket to New York, he went to the hotel for the night. His deep religious faith caused him to believe everything would result for the best. Great was his amazement when the next morning, the daughter of the Commissioner of Patents congratulated him on his success; the Senate

at the moment of closing, March 3, 1843, had passed the bill without debate, providing $50,000 to construct the experimental line from Washington to Baltimore. His gallantry permitted the same young lady, who was first to acquaint him with his good fortune, to frame the first message, which was sent May 24, 1844, between these two cities. It was "What hath God wrought." Thus was electric communication launched.

The revenues from the line for the first four days[1] amounted to 1 ct., on the fifth to 12½ cts. (the sixth was the Sabbath), on the seventh to 60 cts., and the eighth to $1.32. The telegraph was under way; it grew rapidly; it made fortunes for Morse and others connected with it; Ezra Cornell, who was Morse's superintendent of shops, entered the business, became wealthy, and endowed Cornell University with a desire to provide first-class instruction in practical sciences.

The first Atlantic cable was laid, after two previous unsuccessful attempts, in 1865. The cables laid at this time broke after about 5 to 10 years of service, but more permanent ones were laid later until now many cables afford communication service between the two continents. Thomas A. Edison, who began his career as a telegrapher, greatly improved the telegraph by devising means of transmitting more than one message on a line at the same time.

Telephone. Professor Alexander Graham Bell, a teacher of speech in Boston, became interested in transmitting musical tones electrically and was thereby led to the conception of transmitting articulate speech over the wire as an improved telegraph. To accomplish this he saw required the transmission of an undulating electric current whose strength would correspond to the

[1] Reid, James D., "The Telegraph in America."

pressure of the sound wave in the air. After much experimenting, he found that a thin iron disk fixed near an electromagnet would vibrate from the sound waves in the air and induce a corresponding varying current in the adjacent electromagnet. This latter varying current flowed through the line to a similar magnet at the other end, which vibrated a corresponding disk, causing sound waves to be created similar to those which entered the first transmitter. He obtained his patent in 1876, and the first overhead line (Boston to Cambridge) was opened that same year.

Like the telegraph, the telephone was born of faith. Professor Bell and his assistant Thomas A. Watson, an instrument maker, had their experimental equipment set up in two rooms of a garret. They were endeavoring to send musical notes through the wire by vibrating a flat steel spring over the pole of an electromagnet, which they expected to be picked up by a similar spring or reed carefully tuned at the other end. Mr. Watson tells the story as follows:[1]

On the afternoon of June 2, 1875, we were hard at work on the same old job, testing some modification of the instruments. Things were badly out of tune that afternoon in that hot garret, not only the instruments, but, I fancy, my enthusiasm and my temper, though Bell was as energetic as ever. I had charge of the transmitter, as usual, setting them squealing one after another, while Bell was retuning the receiver springs one by one. One of the transmitter springs I was attending to stopped vibrating and I plucked it to start it again. It didn't start, so I kept on plucking it, when suddenly I heard a shout from Bell in the next room, and then out he came with a rush, demanding, "What did you do then? Don't change a thing. Let me see!" I showed him. It was simple. The contact screw was screwed down so far that it made permanent contact with the spring, so that when I snapped the spring the circuit had been

[1] Watson, Thomas A., "The Birth and Babyhood of the Telephone," American Telegraph and Telephone Company.

unbroken while that strip of magnetized steel by its vibration over the pole of its magnet was generating that marvelous conception of Bell's—a current of electricity that varied in intensity precisely as the air was varying in density within hearing distance of the spring.

And so the telephone was born.

After that, experimentation took definite form and renewed zest. The next March witnessed the first recognizable sentence sent by wire. The two experimenters were at work, when the assistant heard Mr. Bell say, "Mr. Watson, please come here, I want you"—a very undramatic, prosy sentence, standing in marked contrast to the lofty sentiment "What hath God wrought," which went over the telegraph.

The telephone, exhibited (1876) at the Centennial Exposition as an interesting toy, largely as a concession to Professor Bell's influential father-in-law, had been accorded an obscure space and was receiving scant attention, when occurred the much-advertised visit of Dom Pedro, Emperor of Brazil, the social event of the Exposition. Some years before, this ruler had visited Professor Bell's speech institute and had been much impressed with the great work that he was doing for deaf-mutes. Therefore, much to everyone's surprise, when His Brazilian Majesty with a great retinue was touring the Exposition and came upon Exhibit No. —, which consisted of Professor Bell and his toy, he approached the inventor with open arms, saying, "Why, Professor Bell, I am glad to see you again." His Majesty, on having the instrument explained to him, was interested in trying it, so he held the receiver to his ear while Professor Bell went to another room to speak into the transmitter. With typical Latin emotionalism, His Majesty with a wild gesture, exclaimed, "My God, it talks." The incident wrought wonders. Royalty had

entered the stuffed quarters. Distinguished scientists also listened, and the telephone got recognition. Lord Kelvin, one of the judges of the electrical exhibit,

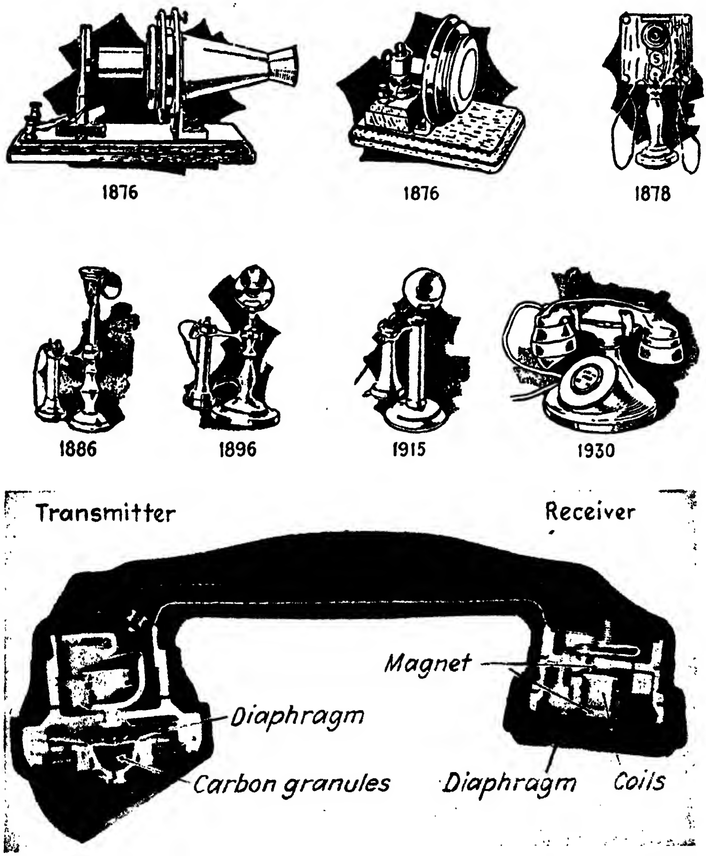


FIG. 24.—Development of the telephone. The most notable developments in the telephone have occurred back of the scenes in the central switching and in the cable with its relays for long-distance conversation. The modern desk phone is a marvel of ingenuity, reliability, and compactness.

reported before the British Association "With my ear against this disk, I heard it speak distinctly several sentences." D. E. Hughes of England and Emil Ber-

liner of United States contributed much to the perfection of the transmitter and receiver. Figure 24 illustrates the development of the telephone at successive decades.

Telephone Systems. The first switchboard, installed (1878) at New Haven, Conn., with eight subscriber lines, was but a crude forerunner of the modern switchboard with 10 thousand lines and of the automatic switchboards. Long-distance telephony was greatly advanced through the invention by Prof. M. I. Pupin, of Columbia University, of the loading coil, which, together with the vacuum amplifying tube placed as relays at intervals along the line, permits the amplification or restoration of the strength of the impulse being transmitted. In this way the magnetic impulses at the end of a transcontinental line may be as strong as or even stronger than the original impulse. Telephone systems became possible through the development of the switchboard by C. E. Scribner and, later, the invention of automatic or machine switching by A. E. Keith, a young electrical engineer in Chicago. Telephone service was inaugurated between New York and London in 1927 and since then has been farther extended internationally.

Wireless Telegraphy. Guglielmo Marconi, an Italian engineer, has credit for inventing the wireless telegraph (1896) when, at age twenty-two, he devised the essential feature, the elevated wire antenna. He successfully communicated across the English Channel in 1899 and across the Atlantic in 1907. His transmitter consisted of a spark-gap device for sending waves of a predetermined length through the ether while the original receptor was a "coherer" without antenna. With this device he sent telegrams using the Morse code.

Wireless Telephony. Paulson, a Danish inventor, bears much the same relation to wireless telephony that

Marconi does to wireless telegraphy. Transmission of spoken words by electromagnetic waves through space instead of through wires developed in the present century through the contributions of many scientists and represents an intermediate stage between wireless telegraphy and radio. The future of sending the voice through the air lay not in conversing person to person but in broadcasting so that all who cared to listen might hear. Wireless telephony has developed chiefly as a means of communication by short wave lengths across the ocean where wires are impracticable.

Radio. About 1875, James Clerk Maxwell, Professor of Physics at Cambridge, demonstrated theoretically that electromagnetic action traveled through spaces as transverse waves having the same velocity of light. About 15 years later, Heinrich R. Hertz, Professor at Bonn, corroborated Maxwell's theory and actually produced such waves, which are frequently called "hertzian" waves. Wireless telegraphy, radio, and television are the practical results of these researches.

Although wireless telegraphy could send signals, voice transmission by electromagnetic waves was hampered because of deficient strength of the wave. The solution of this difficulty came with the invention and perfection of the vacuum tube with the thermionic grid, by Lee De Forest in 1906–1909, an electrical engineer of New York.

De Forest, a young electrical engineer, about three years out of college, felt that he could devise a better receptor than the Marconi coherer for wireless telegraphy. He was engaged at $10 per week for the Western Electric Company at Chicago, living on $8 and spending $2 on experimentation in his room. Working late one night, he pulled the table, holding his apparatus, to the

center of the room directly under the gas light. His electric sparking transmitter was in the adjoining closet. He observed that the sparking of his coil in the closet caused the gas light to dim and flicker. The phenomenon first annoyed him and then interested him, and he became impressed with the idea that a heated gas might be made the most sensitive receptor. From this incident ultimately came the thermionic grid in a tube—the marvelous amplifying tube—because De Forest inquired "why" with respect to a simple phenomenon and rationally proceeded to find the answer to his inquiry. De Forest offered to sell his patent to Westinghouse, the reputed electrical genius of the day; but after freezing the timid young engineer in an interview and a delay of several weeks, the great man decided that he was not interested.

In recent years, the transmission by short-wave radio of conversation across the ocean and improvements in loud speakers have brought the whole civilized world into close communication.

Television. To J. L. Baird, a Scottish scientist, much credit is due for the initial steps of television. In 1926, before the Royal Society, he gave the first practical demonstration of light and shade transmission by means of electromagnetic waves. In the telephone there is a transmitter which converts the energy of *sound waves* of voice in the air into electromagnetic waves which are carried along the wires to a receiver which converts the *electromagnetic waves* back into sound like those originally received; in radio, a similar transmitter converts *sound waves* of voice into *electromagnetic* waves which from the antenna are carried through space, picked up by an aerial of a receiving set, which converts them back into *sound waves* similar to those originally received.

In television, the process is analogous. A transmitter converts *light impulses* reflected from light and shade on a subject into *electromagnetic waves* which may be sent either over wires or through space, picked up by an aerial, and reconverted into light and shade effects. The variations in light and shade being made apparent by the waves received, a picture of the subject is reconstructed. The photoelectric cell which has been developed in the present century is the instrument that converts the light into electromagnetic impulses, and another electronic-tube device reconverts the electromagnetic waves into light. Although numerous scientists are working to perfect television, the progress made thus far does not warrant the expectation that television will soon, if ever, furnish broadcasts of vision corresponding to the great diversity of radio broadcasts of sound.

Signaling. The ancients had elaborate codes of signaling by wigwags and by reflecting sunlight from polished surfaces. Modern signaling is almost entirely by electrically controlled semaphores and lights. A railroad is divided into blocks of variable length depending upon visibility, and in each block the rails constitute an electric circuit. When a train enters a block, a short circuit between the rails through the wheels and axles cause the signals to drop to the danger, or "occupied," position; and when the train passes out of the block, a small motor runs the signals to the safety position. The direct-current track signal system, invented by William Robinson, a Brooklyn engineer, came into extensive use, but it has been almost replaced by the alternating-current system, invented by J. B. Struble, a Pittsburgh engineer. The development of railway signaling, interlocking of switches, and automatic train control has been the result of cooperative or company effort more than individual,

and hence personalities enter to a lesser degree into the record than in the case of most inventions.

Highway and street intersections under heavy traffic are controlled by time signals, electrically operated, and considerable progress has been made in an experimental way in the development of signals for street intersections

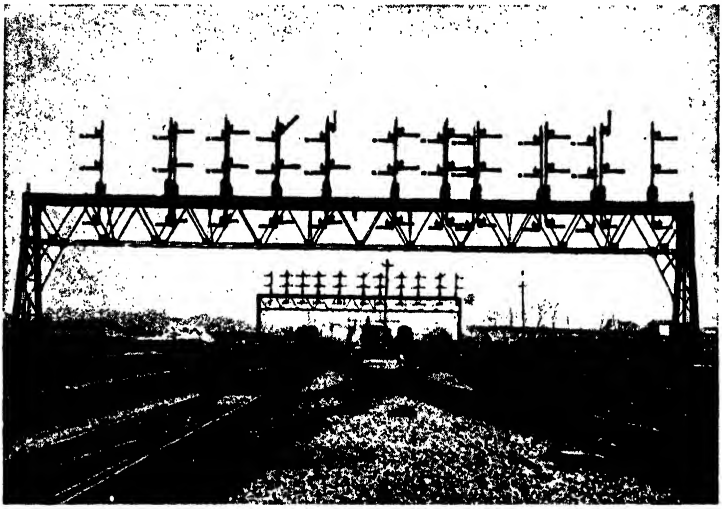


FIG. 25.—Modern signal bridge. For railway, highway, and other traffic movements, signal communication is essential.

that will be operated automatically through photoelectric cells by the approaching vehicles rather than by a clock mechanism.

Teletypewriter. Although the Morse code telegraph was an epochal advance in communication, since the introduction of the teletypewriter, in 1910, it has become nearly obsolete except in the smaller towns. Under present-day telegraphic procedure, the operator sending a message obtains a clear line through to the destination of the message and proceeds to write the message on a machine resembling an ordinary typewriter. This not

only types the message there but also perforates a ribbon of paper in such a manner that the perforations cause electric impulses to operate a similar machine in the distant receiving office, which likewise types the message on a ribbon of paper and gums it automatically to the standard message form. More than 90 per cent of the 200 million annual Western Union messages are handled in this automatic manner. Long messages can be thus efficiently and easily transmitted, so that presidential addresses, legislative acts, and other important documents can be transmitted accurately and cheaply to the newspapers all over the country.

Photography. The camera obscura, or dark box with a hole in one side, by which images could be thrown inverted on the opposite side, came down as a scientific toy from the ancient Greeks. Light was observed to fade colors; hence the idea that the image could be recorded arose. Many people experimented. Among them Louis Daguerre, a French scene painter, happened one day in 1838 to lay a silver spoon on a metal treated with iodine and found the spoon's image was printed on the iodized metal. Guided by this lead, his experiments produced the first crude photographs. The development from that elementary beginning to instantaneous pictures and the moving picture has been gradual. In 1872, some devotees of horse racing at San Francisco were discussing whether all four feet of a running horse ever left the ground at once. They set up a battery of 24 cameras along a track so that the running horse broke strings that snapped the cameras. The experiment not only showed conclusively that at times all four feet are off the ground, but it showed the possibilities of using rapid exposures to depict motion. This stimulated a number of inventors whose efforts culminated in the

invention of the motion picture by C. F. Jenkins in 1894. From these simple beginnings came the factories, the lighting, the stage installations, which employ today many chemical and electrical engineers. Likewise, by means of the stroboscope and other slow-picture devices, motions of machinery and other rapidly moving parts too quick for the eye can be studied in detail. Motion pictures in analyzing and improving manual movements in industry have proved exceedingly helpful.

High-speed photography with a millionth of a second exposure can picture a bullet in flight; high-speed X ray can picture the passage of a projectile through armor plate.

CHAPTER XII

ACHIEVEMENTS IN CHEMICAL ENGINEERING

Introduction. The youngest of the recognized major divisions, chemical engineering, has many great achievements to its credit. As in other branches of engineering, some of the achievements had their prototypes in the old days of alchemy, but the scientific treatment of recent decades has enhanced their value. Some of these will now be briefly mentioned.

Cereal Food Products. In recent years, specially prepared foods from cereals have been extensively manufactured in America. These range from preparations from one cereal, such as rolled oats and shredded wheat, to rather highly wrought foods, but all require chemical control and treatment.

Corn starch, corn sugar, sirups, and numerous other cereal products are typical chemical-engineering achievements through the use of huge tanks, washeries, and evaporators.

Modern milling, likewise, has advanced to a complex art requiring careful heat and chemical control. The variety of flours and other cereal products for special purposes are the direct result of advance in food chemistry.

Sugar. The sugar industry, both from cane and from beets, is one of the large industries of the world. The ancients used honey and certain fruits for sweetening until cane sugar was introduced from India or China about the sixth century A.D. However, cane sugar remained a coarse unrefined material until subjected to

the chemistry of the nineteenth century. The process of purification with milk of lime to prevent fermentation, whitening with bone black, and preparation for market, as well as that of utilizing the by-products of sirups and molasses is one of chemical engineering. Figure 26 shows the interior of a modern sugar refinery.

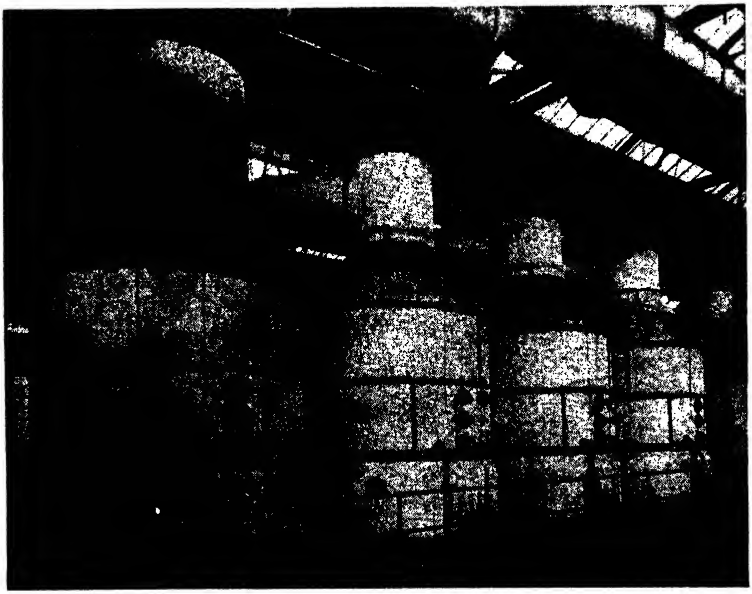


FIG. 26.—Evaporators in a sugar refinery. The granulation and other qualities of sugar are largely controlled by the boiling process.

Dairy Products. In few fields has there been greater progress than in the manufacture of cheeses, confections, and other dairy products, as the result of the advance in the application of chemistry to the industry. Reconstituted milk has been used under circumstances, such as warm climates, where the storage of natural milk was difficult. The milk powder, formed by evaporation of separated milk, is shipped in barrels without special care. The process then consists in remixing the milk

powder with unsalted butter fat and water, and the product is scarcely distinguishable from natural milk. Milk sugar (lactose), casein, and other dairy materials are utilized by the chemical engineer in foods and in commercial products.

Recovery of Wastes. The recovery of industrial and agricultural wastes is a problem within the province of the chemical engineer and often offers rich opportunities. Some of the dump piles from copper refining have proved sources of wealth through improved methods of extracting the metal, and the utilization of the by-products of petroleum, steel, and coal-tar industries has yielded much wealth. The utilization of straw, corncobs, oat hulls, sugar-cane bagasse, flax shives, cottonseed, sawdust, paper-mill, slaughterhouse and tannery wastes has been of great economic value. The term "chemurgy" has recently been coined to apply to the chemical processes involved in converting agricultural products into articles of merchandise and in utilizing agricultural wastes.

Beverages. The manufacture of beverages, especially nonintoxicating, which has developed in recent years to extensive proportions, may be considered a direct achievement of chemical engineering. Their substitution for alcoholic beverages, with the growing temperance of the world, has resulted in notable social and economic effects. Brewing, distilling, and wine manufacture are old arts, antedating modern chemistry.

Packing Industry. Not only in the primary products of the packing industry but more especially in the utilization of the by-products does the chemical engineer find a field of operation. It has been more or less facetiously said by those engaged in the industry that the profits of meat packing are derived from the economical

utilization of the wastes through conversion into marketable by-products. Converting the hides into leather, the bones into gelatin and glue, certain other wastes into cleaning powders, and still others into fertilizer indicate the economies accomplished by chemical engineers.

Food Preservation. The process of preserving fresh food by sealing in glass jars was discovered by Nicolas Appert, a French brewer-confectioner, in response to a reward offered by Napoleon Bonaparte for a method of carrying such food supplies for his army on their marches over deserts and mountains where fresh foods were not obtainable.

In the century following, the utilization of chemical control has not only greatly extended and improved the process for fruits, but it has applied canning to vegetables, meats, and sea foods. The process chiefly depends upon sterilization by heat to kill the spores of molds and bacteria. The success in preserving of natural color and flavor has largely been achieved by means of chemical preservatives. The control and regulation of food preservation have reached their present high development largely through chemical engineering.

Other Food Products. The manufacture of many other food products, which either furnish the table with new varieties or else substitute for materials from more natural sources, has made rapid advance in recent years. Typical of these artificial food products are oleomargarine and other butter substitutes, vegetable oils for animal fat, and extracts for flavoring. The vegetable oils are commonly taken from corn, cotton seed, and various other plants. In recent years the preparation and preservation of many staple foods and the utilization of the by-products have changed these old-time methods into processes of chemical engineering.

The Gas Industry. The first use of gas was limited to lighting but, owing to the introduction of the electric light, gas was shifted almost entirely to heating. Liquefied petroleum gas, "bottled gas," a recent chemical product, is being widely used for industrial and domestic purposes. It has a heat value two to three times that of ordinary natural gas. Artificial gas may be made from coal or from fuel oil and consists of combustible gases such as methane, carbon monoxide, and hydrogen. Natural gas contains about 1000 heat units per cubic foot, while coal gas contains only about 600 heat units per cubic foot. Gas technology has developed to an advanced state through the work of chemical engineers.

Coal-tar Industry. For many years, coal tar was a repulsive sticky waste product from the production of coke and of artificial gas from bituminous coal. In 1856, William Perkin, a young English chemist, while experimenting with tar, added alcohol to the black residue appearing in a beaker from some of his tests, and there appeared a brilliant purple color. Retracing his experiments, he formulated the procedure, and thus aniline dyes were discovered. They worked a revolution in the textile industry.

Coal tar is a complex mixture of various hydrocarbons, acids, and basic substances, which yields a variety of useful products under the hand of the chemical engineer. Some of the more important of these, in addition to dyes, are carbolic acid (phenol), creosote, anesthetics, many important medicinal drugs, toluol, benzol, and perfume bases. Thus chemical engineering has converted a nuisance into a benefaction to mankind.

Timber Treatment. The chief cause of decay in timber is the growth of various fungi which live on the cellular substance of the wood. The chemical engineer

has not only found many toxic substances whose application will prevent the growth of these fungi but has given attention to the most economical methods of applying these treatments. Creosote oil (from tar), zinc chloride, and corrosive sublimate (mercuric chloride) are most frequently used. These preservatives are commonly forced into the cell walls by subjecting the timber to immersion under pressure. In this way, the chemical engineer more than doubles the length of the life of timber exposed to weather as ties, piles, poles, and trestles.

Petroleum Industry. After petroleum is extracted from the ground, it is turned over to the chemical engineer at the refinery, who not only procures from it the maximum amount of gasoline, fuel oils, and lubricating oils but also makes marketable products from the remainder, so that there is actually no waste. These by-products include greases, vaseline, petrolatum, paraffin, candle wax, and coke of a superior grade. The breaking down—"cracking"—of the heavier oils to yield gasoline and the use of the by-products constitute a notable achievement in chemical engineering. "Cracking" consists in converting the hydrocarbons of high molecular weight, through the application of heat and pressure, to those of lower molecular weight and, under favorable conditions, may bring the total yield of gasoline up to 85 per cent of the crude petroleum. A large proportion of commercial gasoline is derived from this source, and numerous patented processes are employed. By this method the chemical engineer has shown the way that not only more than triples the gasoline yield but improves the quality as well. The discovery of inhibitors which produce "antiknock" gasoline by preventing premature combustion of the supercombustible hydrocarbons is another achievement of chemical engineering.

Explosives. The invention of explosives should be ranked in importance along with the steam engine and the electric dynamo, for it not only revolutionized warfare but eliminated much of the drudgery of mining, quarrying, tunneling, and other peacetime work.

Fig. 27.—Boiling tubs in a nitrocellulose plant. These tubs, 16 ft. in diameter, serve for boiling the nitrated cotton in the manufacture of fabrics and cannon powder.

Black powder, discovered about the thirteenth century, was the only explosive known until the latter part of the nineteenth century. Being a mixture of charcoal, sulphur, and potassium nitrate (saltpeter or niter), black powder burns slowly and is used for quarry blasting where shattering of the rock is to be avoided.

Nitrocellulose, the basis of most military powders of today, is made by digesting cellulose fiber of cotton in nitric acid. Cannon powder is manufactured from carefully washed cotton fiber and is made with such precision that the range of projectiles can be reliably

predicted and accurately controlled within a very narrow range. Figure 27 shows boiling and digesting tubs (16 ft. in diameter) in a smokeless powder plant.

Nitroglycerin, which is made by combining nitric acid and glycerin, is another explosive nitrate and is the basis of a number of commercial explosives. Alfred B. Nobel, a Swedish engineer, observing that some nitroglycerin which leaked from a container, caked the packing sand, was led to invent dynamite, which is nitroglycerin absorbed in an inert earth. Dynamite and other high explosives are very rapid in combustion and hence are used in blasting in excavation where a maximum shattering of the rock is desired.

Nitrocellulose dissolved in nitroglycerin forms an extremely powerful explosive known as cordite; so does a combination of toluene, nitric, and sulphuric acids, known as T.N.T. The great number, variety of action, and reliability of explosives constitute one of the achievements of chemistry and of chemical engineering.

Soap. Before the era of soap, the prevailing procedure in personal cleansing consisted of rubbing with oil and fine sand, scraping, and anointing with oil. While the use of soap is of great antiquity (a well-equipped soap factory and its product having been found in the ruins of Pompeii), it remained for modern chemical engineering to make its use inexpensive and universal. The quantity used by a nation has been waggishly stated to be the index of its civilization. The first great advance came when the Solvay process was invented for extracting the lye, or caustic soda, by electrolysis from common salt instead of leaching from wood ashes. The further advances contributed by chemistry make possible the utilization of a great variety of vegetable oils in addition

to animal fats. Every step must be under close chemical control to assure a uniform product. The fats and caustic soda are put into huge kettles in carefully determined proportions and heated by forcing in steam at the bottom. In some plants, these kettles hold half a million pounds each and are two or more stories high. After *saponification,* the soap rises to the top and glycerin as a by-product remains at the bottom. The huge slabs of soap are cut into rough cakes and repressed to form.

Soap at a few cents per bar represents products from the South Seas, the salt mines of Michigan, and the packing houses of Kansas City or Chicago, all made into an effective and uniform product through the technical skill and the organizing ability of the chemical engineer.

Artificial Fabrics. Natural silk is being replaced largely by fabrics manufactured by chemical engineers. Rayon (viscose process) is made from bleached wood pulp or cotton linters (short fibers). These are treated with sodium hydroxide and carbon disulfide. The product, dissolved in water, forms a viscous sirup which is forced through minute holes into a mixture of sulphuric acid and sodium sulphate, which reduces the viscous strings to fibers. These are twisted into yarns or wound on spools. Acetate rayon (celanese) is made somewhat similarly, using acetic acid and acetone as a solvent. Nylon is made from noncellulose extracts of coal, benzine, and phenol, plus ammonia. The product is melted and forced through minute holes and solidified as threads in a nitrogen atmosphere. Cellophane is similar to rayon but made in sheets. Artificial wool is made from milk casein, dissolved in sodium hydroxide, forced through minute holes, and hardened in formaldehyde solution.

Oilcloth, linoleum, and similar fabrics are made by applying successive oil-paint courses with rosin on a

heavy cloth. Artificial compositions are also replacing leather to a considerable extent in the shoe industry.

Paper Manufacture. The manufacture of paper from wood, rags, hemp, cotton, or straw is a chemical-engineering operation that has made distinct advance in recent years, particularly in the way of economy and in variety of product. The wood is chipped, digested with chemical solutions that dissolve out resins and sugar-like substances, leaving the pure cellulose which is bleached and washed. The cellulose pulp, after addition of certain materials to render the paper nonporous and opaque, is matted, dehydrated, and pressed on the machine to form paper.

The making not only of ordinary paper for wrapping, printing, writing, insulating, decorating, and building but also of paper boards for crates and boxes constitutes a large part of the industry.

Paint and Varnish Industry. White lead (lead carbonate), red lead (lead oxide), zinc white (zinc oxide), graphite, asphalt, and other pigments, as well as the oil or other carrying fluid, are made in quantity under processes of chemical engineering and under chemical control. Varnish is made by dissolving certain gums or resins in a suitable solvent, such as turpentine. The chemistry of rapidly drying oils has brought to the automobile industry especially a process of great value in expediting manufacture and repairs.

Ceramic and Glass Industries. The manufacture of portland cement, of brick, tile, terra cotta, chinaware, glass and glassware, floor tiles, and other clay and sand products occupies many chemical engineers. While the processes themselves are relatively simple, the control which ensures uniform and reliable results requires refined chemical and physical control. This branch of chemical

engineering is sometimes given the distinctive name of ceramic engineering. A furnace for glass manufacture operates at about 2700°F.

Abrasives. In 1891, E. G. Achison, a young engineer who had come under the stimulating influence of Edison while in his employ as a draftsman, was attempting to make artificial diamonds by heating charcoal and sand together to high heat in an electric furnace. The fused mass was silicon carbide, SiC, later named carborundum, a material of great hardness which is now widely used as an abrasive. Alundum and electrite, a combination of alundum and carborundum, are newer abrasives. The abrasive industry at Niagara Falls where cheap electric power is available has become extensive.

Rubber. The manufacture of rubber goods of great resistance and for a variety of purposes is one of the outstanding achievements of the chemical engineer. The great strength and durability now available in pneumatic tires for automobiles have been important factors in making the automobile useful, popular, and safe; hence the modern automobile tire may be said to be one of the great achievements of the chemical engineers.

Synthetic Rubber. In the endeavor to make artificial rubber, chemists have found it more practical to make rubber substitutes which have most of the properties of rubber and which are referred to as "synthetic rubber." The principal one of these, Buna S, made from butadiene, can replace true rubber for most purposes. Butadiene can be made from either grain alcohol or petroleum. About 2½ lb. of butadiene can be made from a gallon of alcohol, and about 2.7 gal. of alcohol can be derived from a bushel of corn. Hence with a farm yield of 50 bu. of corn per acre, an acre of land in corn would yield about 300 lb. of butadiene, which gives only about two-thirds

as much rubber as an acre in the tropics will produce of natural rubber. The cracking of petroleum yields only about 6 per cent of butadiene, but it produces a large number of valuable by-products; hence, the relative economy of this process depends largely on the market for the by-products. Styrene, the other principal contituent of Buna S, is made by combining ethylene and benzene, the former being chiefly obtained from grain alcohol and the latter as a by-product of the coke industry.

Buna S is a general-purpose synthetic rubber which vulcanizes and has many other properties similar to natural rubber. It is actually superior to the latter in some respects. Automobile tires of Buna S are about equal to those of natural rubber. The development of synthetic rubber on a large scale is a notable achievement of chemical engineering.

Plastics. A proffered reward of $10,000 by a manufacturer to anyone who would invent a substitute for ivory, whose natural source was becoming scarce, caused John W. Hyatt, a printer, to invent celluloid, a combination of camphor and pyroxylin. Dr. L. H. Baekeland, while attempting to synthesize another product, discovered that two liquids, phenol (carbolic acid) and formaldehyde, when combined, made a plastic that hardened into an insoluble, heat-resistant, nonconducting solid. He was at first chagrined by the failure of his experiment but soon recognized the possibilities of his accidental discovery. The process was patented in 1909, and Bakelite has become the most widely used plastic in the manufacture of telephone receivers, receptacles, and similar articles. Durez is another phenol-formaldehyde plastic of wide utility. Casein plastics are made chiefly from milk, although they can be made from soybeans,

peanuts, and other materials. They are used for buttons, yarns, and other articles. Cellulose acetate, developed by G. W. Miles about 1907, has been extensively used for films, textiles, lamp housings, steering wheels, and receptacles. Vinyl resin plastics are used as the inner layer of safety glass and as waterproof sheeting. Phenolic resins are used for molding compounds and as adhesives. The acrylic resins have become increasingly important, owing to their optical properties, for use in gun turrets and wherever transparency and toughness against impact are required. Lucite is one of the most widely used materials of this class. Plastic articles can be metal plated and inlaid. Couplings and many small items formerly made of metal are now molded from plastics. The further developments in plastics will supplement metals and wood to yield a greater variety of products.

Fertilizers. The essential constituents of fertilizers are potash, nitrogen (in compounds), and phosphorus. Recently developed sources of potash in New Mexico and California are convertible by chemistry into forms most useful for plant growth. Nitrogen and phosphorus particularly require chemical treatment for conversion to fertilizer. Nitrogen is synthesized into ammonia by the Haber process through the application of electric power, and recent developments of water power are partly devoted to this industry. Phosphorus is found in phosphate rock and changed into acid phosphate, the form in fertilizers, by the application of sulphuric acid.

Within recent years, special root hormones have been discovered which are potent stimulants of plant growth, but they are too expensive by present production methods for general agricultural use.

Along with fertilizers, chemical engineering is now furnishing many insecticides, fungicides, and other appliances that increase and improve agricultural products.

Metals and Alloys. Most of the principal metals had been discovered and refined before chemistry attained scientific status; although aluminum, magnesium, and many minor metals awaited the coming of the chemical laboratory. Aluminum, first extracted by Hans Oersted in 1825, was purified in 1827 by Friedrich Woehler, who became a famous professor of chemistry at Göttingen. One of his students was Professor Frank Jewett, who brought to his classes at Oberlin College an enthusiasm for the possibilities of this new light metal. In his class lecture, he stated that a fortune awaited the man who could discover a cheap method for the extraction of aluminum. One of his students, Charles M. Hall, said to a classmate, "I am going after that metal." Later in that year, 1886, this twenty-two-year-old student laid a pellet of pure aluminum in the professor's hand. By dissolving alumina (ore) in molten cryolite and electrolizing, he found the process which has been the touchstone of riches. This process, the fruit of a persistent experimentation by an eager inquiring student, was patented and remains today the fundamental basis of the great aluminum industry, which, far exceeding the professor's prediction, has yielded many fortunes in addition to that of Charles Hall. Electrochemistry has been widely used in the production of many metals and their alloys and is one of the more potent instruments of the chemical engineer.

The recovery of magnesium from sea water and from brines has recently been developed on a large scale (see Fig. 28). The sea water is flocculated with lime and filtered. The filter cake is dried, and the metal is

extracted from the $MgCl_2$ by electrolysis. Duralumin and magnalium are important magnesium-aluminum alloys. Dow metal, another alloy, is the lightest structural material available.

Radium and uranium, both radioactive, are extracted by the chemical engineer from the rare ores, pitchblende

FIG. 28.—Filters for separating the precipitated milk of magnesia from the sea water. The magnesia cake is removed from the filters by an air blast. Stacks of cells for extracting metal from cake are at upper right. (*Courtesy of the Dow Chemical Company.*)

and carnotite. If these metals should become the key to the hidden secrets of nuclear energy, their importance cannot be overestimated.

Miscellaneous. Chemical engineering has reduced fire losses by improving extinguishers; made fibers of aluminum and of glass; improved refrigerants, laundry materials, water softeners, and food preservers; made stronger glues and other adhesives; furnished wood, rubber, and other putties and plastics; made vanilla

from wood wastes; and produced vitamins and germicides in abundance. In fact, chemical industries with their furnaces, presses, vats, autoclaves, evaporators, solvents, and filters are daily bringing new and improved foods, fabrics, and other conveniences.

Design of New Materials. The variety of chemical products to be manufactured will be multiplied by the advances in chemistry which virtually permit the design of the molecule according to predetermined patterns and properties. It seems probable that in the future not only will many natural substances be supplanted by synthesized substitutes, but new and improved products will be created for man's convenience. By the process known as polymerization, organic molecules are built up into long heavy molecules from which such materials as synthetic rubber are made. The esters (compounds from alcohols and acids analogous to salts from metals and acids) are an important molecular group from which a number of materials are manufactured, including artificial flavors and vegetable oils. From such elementary units of composition, the chemical engineer designs the materials to be manufactured.

Outstanding Achievements. The following list of achievements of chemical engineering, furnished by Dr. H. L. Olin, Professor of Chemical Engineering at the University of Iowa, are at least representative of those notable accomplishments in that field in recent years which have so greatly added to the convenience of mankind:

1. The LeBlanc and Solvay processes for making soda from common salt.
2. The commercial synthesis of ammonia by Haber through the fixation of atmospheric nitrogen as a basis for fertilizer and explosives.
3. The perfecting of petroleum-oil cracking which greatly

increased the yield of gasoline from petroleum and the improvement of gasoline for internal-combustion engines.

4. The Sabatier process for hydrogenating unsaturated oils to make edible fats from inedible vegetable oils.

5. The conversion of cellulose from wood and cotton into lacquers, plastics, and explosives.

6. The hydrogenation of coal and heavy oils to produce gasoline.

7. The development of modified cellulose to produce textiles such as rayon and cellophane, and of noncellulose materials to produce nylon and similar materials. They have revolutionized the textile industries.

8. The discovery of the phenol-formaldehyde plastics (such as Bakelite), which established the plastics industry.

9. The production of potash from brines and impure salt deposits for artificial fertilizers.

10. The quantity production of magnesium and bromine from sea water yielding strong lightweight metal and alloys and facilitating the manufacture of ethyl lead.

11. The development of synthetic resins, largely from tar and petroleum, from which durable coatings, bristles, and fabricoids are made, replacing natural gums.

12. The production of synthetic rubber substitutes from gasoline and alcohol.

13. Improvements in glass manufacture for improved light bulbs, duraglass, fiberglas, pyrex, and glasses with special optical properties.

14. The high-pressure technique for converting simple gases, such as carbon monoxide and dioxide and hydrogen, into wood alcohol for industrial uses.

CHAPTER XIII

ACHIEVEMENTS IN CIVIL ENGINEERING

Surveying. Surveying ranges in complexity from measuring short distances and small differences of elevation on the surface of the earth considered as a plane (plane surveying) to the complicated surveys which must take into consideration the oblate sphericity of the earth (geodetic surveying). Land surveying, surveys of sites for structures, drainage or irrigation systems, railroads, etc., involve only plane surveying in which the measurements are made as if on a floor instead of on a ball. Geodetic surveying covers large areas and requires that the curvature of the earth's surface be taken into account. The most difficult land or plane surveying is represented by determining property lines in large cities where the records are likely to be obscure, the conditions for making observations very difficult, and the necessity, owing to the high value of the land, of unusual precision and refinement in the results. The more difficult geodetic surveys are involved in determining coast lines by which the shape and size of continents are determined.

A complete system of triangles, 25 to 100 miles on a side, calculated from *one measured base line* gives the general relationship of points over a portion of the earth's surface and the details are filled in from those points. The base line is measured with an accuracy of about ⅛ in. in a mile. Levels are run with great precision from mean sea level.

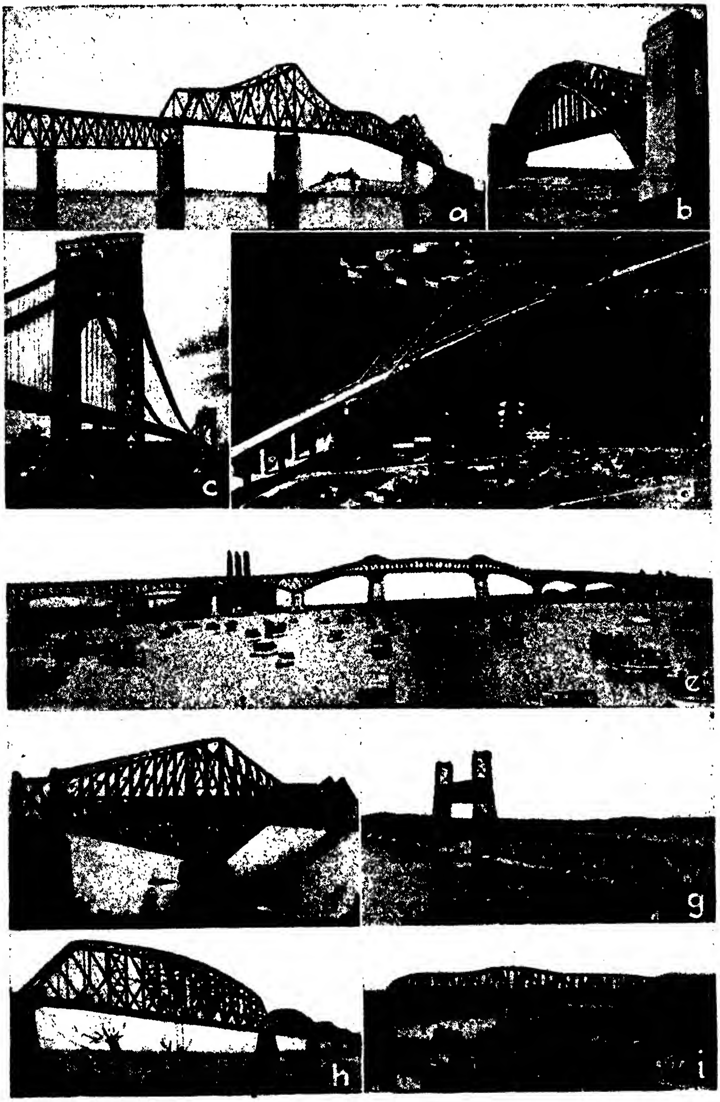


FIG. 29.—A group of notable long-span bridges. (*a*) Charleston Harbor, (*b*) Hell Gate, (*c*) George Washington (Hudson River), (*d*) Bayonne (Kill van Kull), (*e*) Hackensack River, (*f*) Quebec, (*g*) Kennebec River, (*h*) Metropolis (Ohio River), (*i*) Sciotoville (Ohio River).

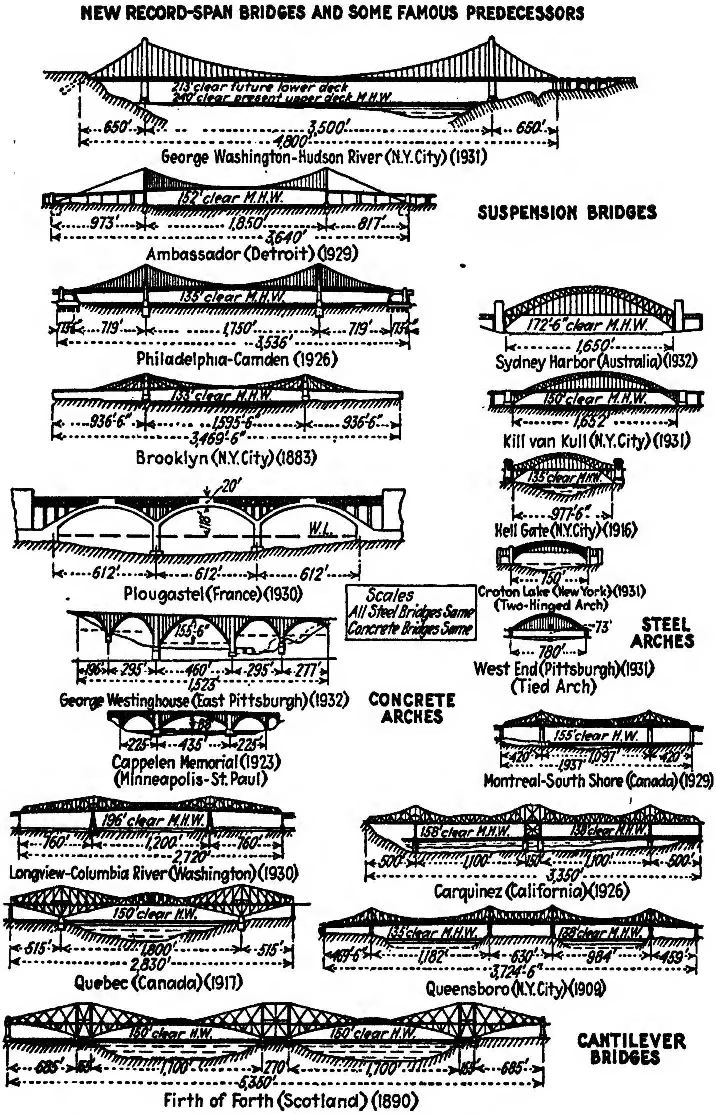


FIG. 30.—Achievements in long-span bridges. Sketches of various types of both steel and concrete structures showing span and general appearance. Golden Gate bridge span will be 4,500 ft.

Recently topographic surveying has been done by photography from airplanes.

Bridges. Great advances have been made in recent years in both steel and concrete bridges. The new Kill van Kull steel-arch bridge at New York of 1,675-ft. span, the Quebec bridge of cantilever type of 1,800-ft. span, and the new Hudson River suspension bridge of 3,500-ft. span mark outstanding achievements in the field of bridge engineering, although the far-famed suspension bridge of 4,500-ft. span over Golden Gate surpasses all others by a large margin. These bridges together with some other notable examples are shown in Fig. 29 and Fig. 30 shows diagrammatically spans of some of the recent bridges of various types.[1]

Buildings. Tall buildings—"skyscrapers"—have become possible through the development of deep foundations that will sustain the enormous loads, the use of steel framework to carry the walls and floors, and the perfecting of elevators that will convey passengers and freight quickly to the upper stories and also through the introduction of fire-proof building materials which eliminate the fire hazard.

An outstanding achievement in high buildings is the Empire State Building of New York which is 85 stories or 1,248 ft.—nearly a quarter mile—high. It is supported by a steel framework which rests on piers extending to bedrock. This is the highest structure in the world at present. Figure 31[2] represents diagrammatically some notable achievements in height of buildings.

Foundations. An important factor in making possible tall buildings and long bridges has been the development of the art of sinking foundations through water-bearing

[1] *Eng. News-Record*, Feb. 4, 1932.

[2] *Civil Eng.*, March, 1931.

soils to solid rock. This is usually accomplished by the pneumatic-caisson process, which consists, in principle, of inverting a huge airtight box, called a *caisson*, the size of the bottom of the pier and sinking it by building the pier on top and keeping water or mud from flowing up inside by maintaining air pressure on the working chamber. Men work inside under the air pressure and excavate the spoil, which is removed through air locks.

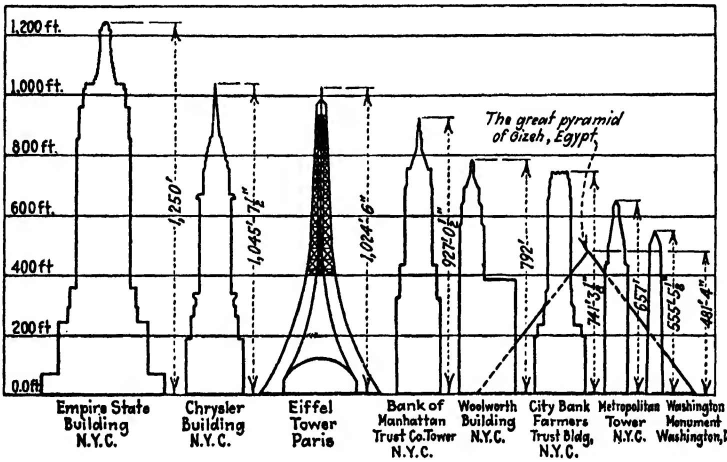


FIG. 31.—Achievements in high buildings. Advances in foundation construction and elevator design have made high buildings possible.

In this way, piers can be carried down to bedrock, so long as the pressure does not exceed about 50 lb. per square inch (110 ft. below water line), which is about the maximum in which men can safely work.

Tunnels. Tunneling under mountains in solid rock consists chiefly in blasting down the rock and hauling it away, the chief problem being the economic handling of the spoil. Tunneling under the bottom of a broad river through soft earth saturated with water is a more difficult achievement. Numerous tunnels under the East River and under the Hudson River at New York

might be mentioned, but the Holland vehicle tunnel (named for the chief engineer Clifford Holland) under the Hudson River is perhaps the most notable. This tunnel, consists of twin tubes each 29 ft. 6 in. in diameter carry-

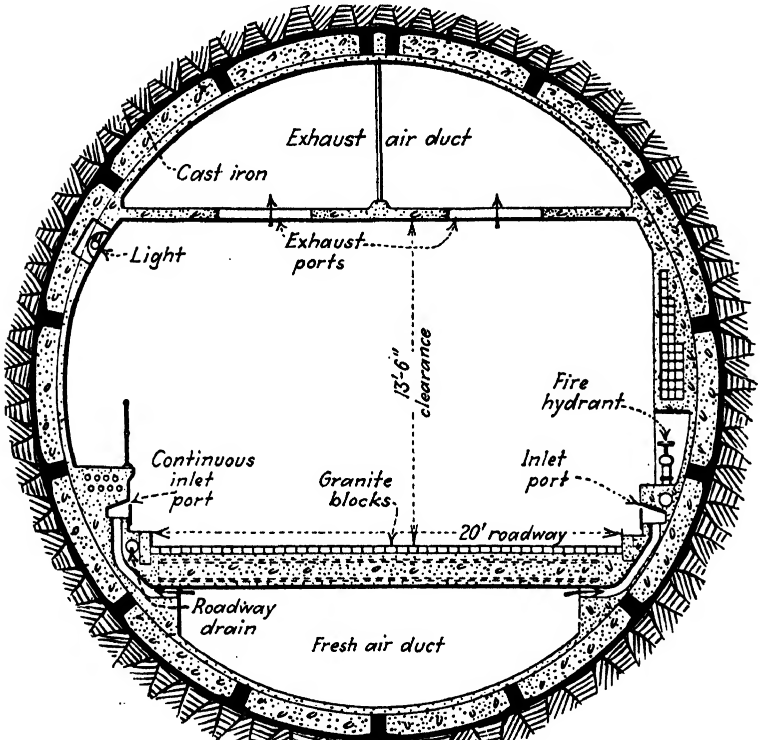


Fig. 32.—Cross section of the Holland tunnel. Ventilation, lighting, and other services make such a vehicle tunnel usable.

ing a two-way street and sidewalks. It was driven by forcing a large cylindrical shield through the earth, excavating the spoil inside the cylinder at each forward push, and lining the tunnel as it was excavated. The tunnel accommodates many million vehicles yearly and cost about $42,000,000. The ventilation system, which

removes exhaust gases and keeps the air wholesome, required extensive experimentation to insure its success. Figure 32 represents a cross section of the Holland tunnel and indicates the engineering features that must be provided in such a structure.

Water Supply. A diagrammatic sketch of the essential features of a typical water-purification plant is shown in Fig. 33. The difficult problem of securing an adequate

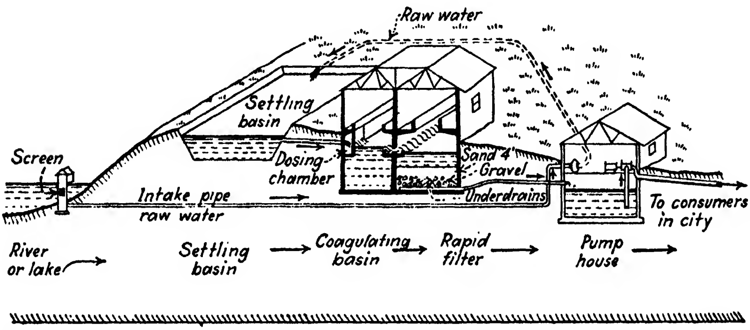


Fig. 33.—Diagrammatic sketch of a water purification layout showing general features of the process. Local conditions determine the details of the plant.

public water supply for a large city is illustrated by the cases of New York and Los Angeles. Cities situated on large lakes and inland streams can use the water from these sources after it has been purified by sand filters, but cities situated on salt water must go far inland to secure an adequate supply. The present supply for the city of New York is from rivers in the Catskill Mountains about 100 miles away, which are impounded in large reservoirs by a high masonry dam. The water is then brought through a large conduit, passing under the Hudson River about 1,100 ft. beneath the surface of the water and thence down to the city. It is then distributed through tunnels and pressure mains to the city. The city uses nearly a billion gallons of water per day, the

equivalent of a river of considerable size. The Catskill supply cost over $200,000,000.

At the other side of the country is Los Angeles, which was compelled to go into the mountains and bring the waters of Owens River 250 miles across rugged country, through a closed conduit, tunnel, and open aqueduct to the city at a cost of about $25,000,000.

The great achievement from improved water supplies is the reduction of the devastating scourges of typhoid fever and cholera. In recent years, air purification to prevent respiratory diseases, mosquito control for malaria, insect and rodent extermination, and noise abatement to lessen nervous disorders are being included in sanitary engineering.

Sewerage. The word *sewage* refers to the fluid in the sewers; *sewerage* means the whole system and comprises the sewers, the treatment plant, and other devices for removing and disposing of the sewage. As population increases in a region, the adequate disposal of sewage increases in importance. Cities located on the seacoast or on large rivers usually discharge their sewage untreated into the sea, but inland cities are compelled more and more to treat their sewage in special plants in a way to deprive it of its harmful possibilities. Sanitary sewage is the spent water supply of a city, with the wastes it has collected; storm water is the runoff from rains.

Storm-water sewers collect rain water through inlets at street corners and carry the water without treatment to some natural stream or watercourse. Sanitary sewage, on the other hand, which is collected from houses, offices, and institutions and frequently includes industrial wastes also, should generally be treated before it is discharged into a natural watercourse. The extensive system of main trunk sewers and tributary sewers in a

large city and the plant for treatment constitute an important engineering project since every city has its own peculiar conditions to be provided for. Figure 34 shows a schematic section of a typical sewage-disposal plant.

Hydraulic Power. To permit hydraulic power to be developed economically, there must be a sufficient and fairly uniform flow of water at a proper head or fall, and

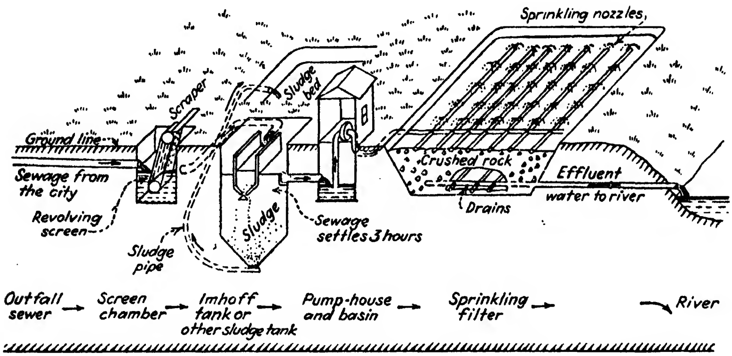


FIG. 34.—Diagrammatic sketch of a typical sewage treatment plant. Details are made to suit local conditions. The degree of purification required largely influences the kind of treatment to be chosen.

there must be an adequate market for the power in lighting cities and operating industries near at hand. Economies in generation are quickly lost in the cost of transmission to considerable distances.

The largest hydraulic power plant, the Conowingo plant on the Susquehanna River, 70 miles north of Philadelphia, develops 378,000 hp. (see Fig. 35). The flow of the river varies between 2,200 and 750,000 cu. ft. per second, and the head, or fall, is about 90 ft. The plant consists of seven water turbines of 54,000 hp. each. To use this variable amount of power satisfactorily, it is necessary that the plant be tied in electrically with

steam plants which will supply deficiencies in power during low water.

High-head plants in mountainous regions bring the water in a closed pipe, sometimes under 2,000 or 2,500-ft. head.

River Improvement and Flood Control. In order to safeguard life and property along the banks of large rivers, protection and control works must be constructed.

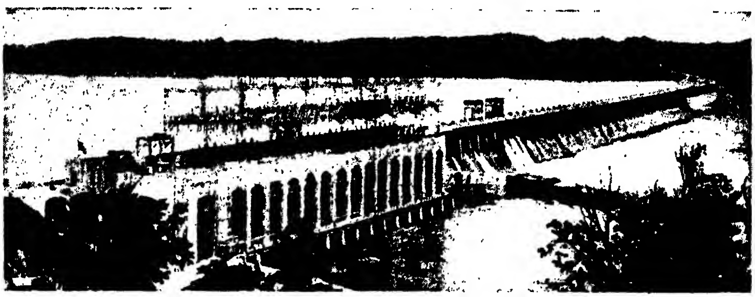


Fig. 35.—Conowingo hydroelectric power plant, one of the largest in the world.

These usually consist of (1) levees along the banks, (2) channel improvement to permit a more rapid escape of the water, and (3) control reservoirs designed to hold the water for a time and to release it at a rate which the channel will carry. The largest river-improvement and flood-protection project now under way is the Mississippi. Levees, bank protection, supplementary spillways near the mouth, and overflow-storage areas constitute the devices being used. The lower river is in an area of heavy rainfall; consequently, the heaviest inflow comes from that region and compels most of the improvement works to be located below Cairo.

Dams. Dams may be built to store water or to divert a portion of a stream into a canal. They may be built of earth (for low heights), of loose rock fill, and of

masonry. Masonry dams may be gravity walls whose resistance to overturning and sliding is sufficient to withstand the pressure of the water above the dam, or they may be arched between canyon walls, sustaining the water pressure by arch action, much as a bridge does the loads placed upon it. The Boulder Canyon dam in the Colorado River is the highest dam in the world. It is about 730 ft. high and 650 ft. thick at the bottom. It is arched in plan but has a gravity section. The Bridge Canyon dam will be 736 ft. high.

Irrigation and Drainage. Not infrequently, the land that is most fertile and most favorably situated with respect to growing temperatures is either deficient in natural rainfall or, in other regions, is swampy with an excess of water. In the first case, water must be brought on the land by irrigation and, in the second case, the excess water must be removed by drainage.

In irrigation, the flow of water in streams is stored through the early season and brought out into the district through a large canal and distributed through smaller distributaries to the field laterals by means of which the fields are actually flooded to a depth of perhaps 5 in. about three times during a growing season. Drainage works are virtually similar but with the direction of flow reversed. The technical problems involved may or may not be difficult, but the factors that determine whether or not an irrigation or a drainage district will be economically successful are complex and require experienced judgment.

Railways. The construction and maintenance of railways require the work of many civil engineers and involve a great diversity of work. The choice of grades and curve and other location features that will permit the traffic to be hauled at minimum cost, on the one

hand, is a complicated engineering problem, while the routine operations of aligning track, on the other, are relatively simple; all degrees of complexity lie between these extremes. Many existing railways need revision, and improvement of location as traffic increases in density and other radical changes are needed to make railroads serve modern transportation requirements.

Perhaps the most pressing type of problem for civil engineers in railroad service at present is the design of more efficient terminals. When one considers that freight cars are actually in motion somewhat less than a tenth of the total time and are standing for loading, unloading, or other purpose the remainder of the time, one recognizes the need for efficient yards and terminals. Generally, the terminals are the features that limit the transporting capacity of a railroad.

Highways. The building of surfaced highways during the present century since the advent of automotive vehicles has been a notable achievement. Much experimentation was necessary to determine the proper design of the pavement slab, the behavior of foundations, the action of frost, and many other matters. The greatest problems of the future lie in operation and safe traffic control. The great diversity in vehicle characteristics with reference to size and maneuverability, the personal factor of the driver, and a lack of uniformity of legislative regulations complicate operations. Safety of operation, the proper adjustment of license fees to wear of road and to the amount of occupancy of the capacity of the road, the caring for vehicles of different speeds, provision for parked cars, etc., are typical problems of today. At present, there are about 31 million automotive vehicles registered in the United States which contribute annually about 400 million dollars as license fees. The total

length of roads in the United States amounts to about 4,000,000 miles, of which nearly 400,000 miles are surfaced. City streets total about 300,000 miles. Federal aid roads amount to about 100,000 miles.

Waterways. Small artificial canals served transportation needs effectively in prerailroad years, but only those waterways which accommodate large self-propelled boats can be made economically serviceable at the present time. The Suez Canal, the Panama Canal, the Great Lakes, and the estuaries of large streams are typical examples. The program of inland waterways on the Mississippi and its larger tributaries now under construction will be the most extensive inland waterways ever built. To what extent they will meet present traffic demands cannot definitely be predicted. The proposed Saint Lawrence waterway, which will admit ocean-going vessels of about 27-ft. draft, will permit most of the ocean shipping to load directly to and from lake ports. Obviously, the completion of this waterway will have a great influence on transportation routing in the United States.

Airports. With the growth of aviation, the design of airports is becoming a specialized field of civil engineering, and the rules of operation to avoid congestion and accidents are emerging from study and observation. Airports must provide runways at various angles to accommodate takeoffs and landings with the wind in any direction, hangars and facilities for fueling and servicing planes expeditiously, restaurants and other conveniences for the traveling public, and facilities for cargoes. A drainage system adequate to remove ground water and surface water from the heaviest rains must be provided. One of the large airports, at San Diego, has a main run-

way 8,500 ft. long by 200 ft. wide. Where the runway passes over soft ground, the concrete pavement is 12 to 14 in. thick to sustain the heaviest loads. Taxi pavements 75 ft. wide extend the full length of the field. In the future, changes in plane design may diminish the length of runways required. The location of airports relative to urban populations and to railway stations requires careful engineering analysis and judgment.

Construction. Construction methods and organization have advanced to such a high state of efficiency that they constitute an important phase of civil engineering. Drills, dredges, and power shovels for excavating, with dump trucks and cars for hauling, and scrapers and bulldozers for leveling, facilitate earth removal; elaborate mixing, conveying, and placing equipment expedite concrete work; gin poles, cranes, and derricks do the hoisting in steel erection. Inasmuch as work costs about a hundred times as much when done by men as when done by a gasoline engine or an electric motor, it is economical to use mechanical power wherever possible.

The contractor's organization for a large project usually comprises a superintendent in charge, with area-superintendents coordinating operations on the main subdivisions, and foremen directing gangs of workmen and their helpers on specific parts. Timekeepers record the hours worked for each employee and help prepare the pay roll. The superintendents are frequently trained engineers. The owner is represented by a supervising engineer, assistants, and inspectors, who make monthly reports on the progress of the work as a basis of partial payments to the contractor.

The concern of the superintendent of construction is (1) to get the work organized and laid out so that the

various gangs can proceed without interfering with each other, and (2) to pile or store materials so that any particular items will be conveniently accessible without moving others. A superintendent of construction requires experience and qualifications other than technical for which civil engineering training is a good foundation.

CHAPTER XIV

ACHIEVEMENTS IN ELECTRICAL ENGINEERING

Introduction. The achievements in electrical engineering during the past half century have been so marvelous that they have greatly changed the mode of living in civilized countries. Many of these are so spectacular that they have already been made familiar through the columns of the daily press and of popular magazines, while others, even more important in many respects, have received scant attention. Only a brief survey of the field can be made in this chapter.

Generators. The generating of electrical energy, *i.e.*, the conversion of the mechanical energy of a rotating generator into electrical energy, represents an important function of electrical engineering. As previously indicated, the size of generating units has gradually increased from the beginning to the present. An outstanding example is the 160,000-kw. (210,000-hp.) steam-turbine generator unit of Brooklyn Edison Company at New York. This generator operates at 1,800 r.p.m. and the one unit exceeds in capacity the entire generating plant of the famous hydroelectric plant on the Mississippi at Keokuk. Figure 36 shows a 66,600-kva. generator in process of assembling.

Transmission. Because electric energy can be transmitted more economically at high voltage (potential) than at low, the current is transformed, or stepped up, from relatively low voltage at which it is generated to high voltage for transmission, *viz.*, from about 660 to

2,200 volts for older practice, and to 11,000, 22,000, 66,000, or even 132,000 volts for more recent practice. Since electric energy cannot be used safely and practically at high voltage, it must be transformed, or stepped

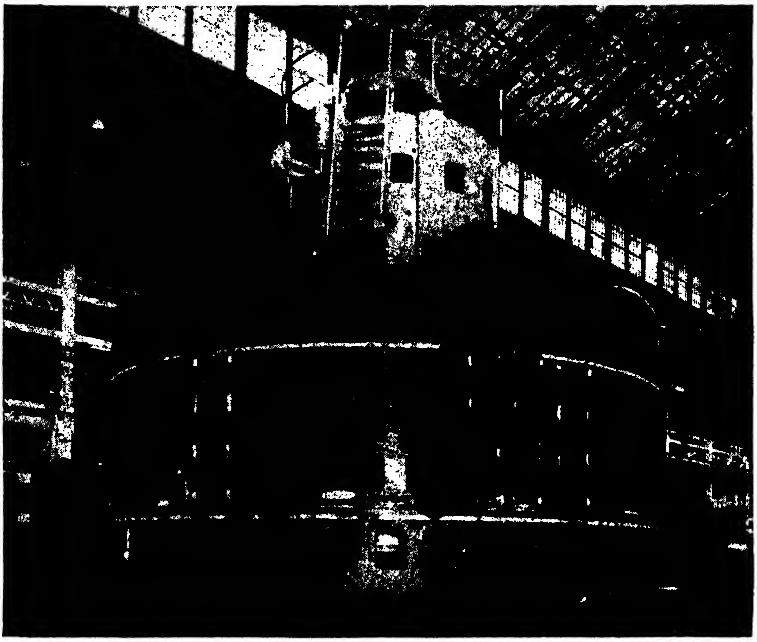


FIG. 36.—Electric generator. Mechanical as well as electric problems are involved in making a large rapidly revolving electric generator.

down, at the distributing end of the line to a usable low voltage, *e.g.*, 110 or 220 volts.

The development of transformers to handle this power efficiently, insulation of conductors and insulators at supports, lightning arresters, and cable manufacture have kept pace with the needs of the industry. Power is now successfully transmitted 250 to 300 miles with the probability that distances up to 500 miles may soon be achieved.

Lighting. The number of incandescent electric lamps sold amounts to more than 500 million per year. An industry of such proportions and variability in requirements is a monument to electrical-engineering achievement. The development of gas-filled lamps, tubular lamps, ultraviolet lamps with accessories and control devices has increased the field for electric lighting. Floodlighting of airports, athletic fields, and buildings has been a notable feature. The use of fluorescent and vapor lights is increasing owing to higher efficiencies.

Street lighting has greatly improved with increased safety for night driving. A large portion of traffic accidents in cities result from inadequate street lighting. Lighting of rural highways is increasing.

Lights are extensively used in traffic control at intersections and in the movement of traffic generally. A system of stop and go lights can be conveniently timed so as to keep traffic moving rapidly and safely. Lighting in theaters and for motion pictures has become so varied and exacting as to constitute a specialized vocation. The illumination of factories, offices, and stores has developed still other specialties.

Central Stations. Economies of operation in furnishing electric light and power are accomplished by generating and transmitting in large units. This fact has given rise to the construction of large central stations, which not only generate and transmit power efficiently, but permit a wide diversity of uses of electric energy, thus promoting maximum constancy and economy in its utilization. For example, if a power plant furnished lighting service only, it would be practically shut down during the day, but by furnishing energy for industries, home motors, and other daytime uses, the plant operates under better load conditions. This situation has caused

electrical engineers to build large central stations, the planning of which demands a familiarity with economic as well as technical procedures and involves many varieties of engineering science.

In handling fuel and ashes, conveyors are used to secure the most economical service and large boiler and turbine units with fuel economizers, insulation, and

FIG. 37.—Central station. Turbogenerator sets of the State Line Power Plant.

other devices for preventing heat losses. The generators are of huge size, and the transformers, insulation, and other features are designed to secure maximum efficiency in generating and transmitting power.

Electric Welding. Electric welding of steel members in structures is replacing to a considerable extent the older process of riveting. Electric welding of steel members to make machine frames and bases has largely replaced iron castings in manufacturing. Over one hundred cities now specify arc welding of steel buildings as a substitute for riveting. Making machine bases by welding greatly reduces the weights and costs.

Electric welding uses the heat liberated in the arc stream at the arc terminals to fuse the metals to be welded and to cause them to flow together. Usually additional welding metal is fed into the arc in the form of a wire so that a welding bead is deposited.

Even thick plates can be welded almost as rapidly as a sewing machine sews a seam, and electronic spot welding will make thousands of "stitches" per minute. Plates on ships now can be welded under water.

Electrification of Railroads. Where traffic is heavy, railroads can be more economically operated by electric locomotives than by steam, but for lighter traffic electrification is not economical because of the great outlay for the central station and the transmission lines. Figure 38 shows a Pennsylvania Railway electrification.

The Reading Railroad has electrified its suburban service at Philadelphia, the Lackawanna at New York. and the Illinois Central at Chicago. The New York, New Haven, and Hartford Railroad, carrying heavy passenger traffic, and the Virginian Railroad, carrying heavy coal traffic, are almost completely electrified. A 440-mile section of the Chicago, Milwaukee, St. Paul and Pacific over the Rocky Mountains is operated by electric power chiefly from hydroelectric plants, and the Pennsylvania Railroad hauls heavy traffic on its electrified lines (220 miles) between New York and Washington. This last is the outstanding achievement in electrification, an entirely new type of locomotive having been developed. For this electrification, 60 freight and 90 passenger electric locomotives of the new type are required. Figure 38 shows the type of locomotive used, representing modern design in electric motive power.

Diesel-electric and gas-electric cars are being exten-

sively used for lighter traffic lines, and trolley busses are being introduced in cities to avoid track maintenance.

Electrification of Industries. Because of the convenience in control and, in many cases, because of economy, industries are tending to install electric motors to operate their machinery. These industries find it

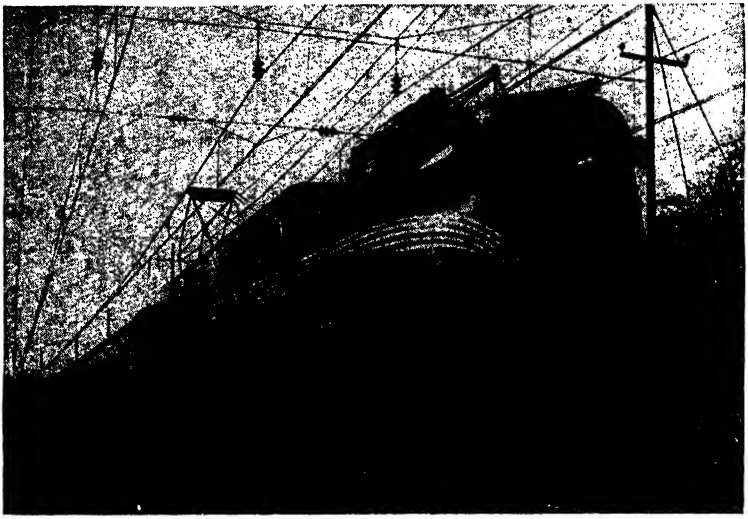


Fig. 38.—Heavy-duty electric locomotive, Pennsylvania Railroad. "Broadway Limited" train and typical catenary construction of electric wires above. (*Courtesy of the Pennsylvania R.R. Co.*)

economical to purchase their electric power from large central-station lines rather than continue their own independent power plants.

Paper manufactures, newspaper press drives, steel rolling mills, and many other types of industry are electrifying on a large scale. The rubber industry, one of the newest, is nearly all electrified. Motors totaling 42,500 hp. operate rolls for the Illinois Steel plant at South Chicago, and a similar installation is used at the Gary Works. Coal-mine hoists are operated electrically,

and the coal is screened, cleaned, and graded by electric equipment.

Electrification of Ships. Electric drive has been extensively used within the past few years for ocean-going ships. The *S.S. President Hoover* (1931), the first all-electric ship for transoceanic service to be built in

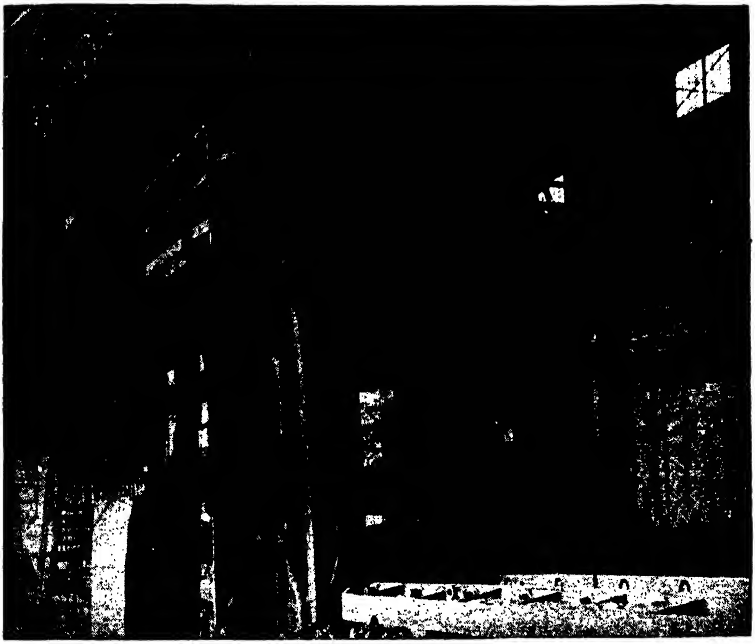


FIG. 39.—Electrified steel rolling mill at Gary. Electric motors operate even heavy machines with reliable speed control.

America, was found in its trial runs to exceed the predicted operating performance. The ship has an over-all length of 654 ft., width 81 ft., and loaded draft 32 ft. The power equipment consists of two turbine generators at 10,100 kw. each, operating at 2,660 r.p.m. with two propeller motors operating at 133 r.p.m.

Electrification of the Home. One of the most important avenues of sales of electric energy results from

the extensive use of electrical devices in the home. Sweepers, heaters, laundry apparatus, fans, ranges, beaters, clocks, and refrigeration, all contribute to the market for electric power. The manufacture of these home devices has grown in recent years to enormous proportions.

Telephone. Improvements in the telephone make it a marvel for satisfactory service. The compactness of a complex engineering device is illustrated in the ingenious design of a modern receiver. The investment in telephone equipment and the services rendered are multiply-

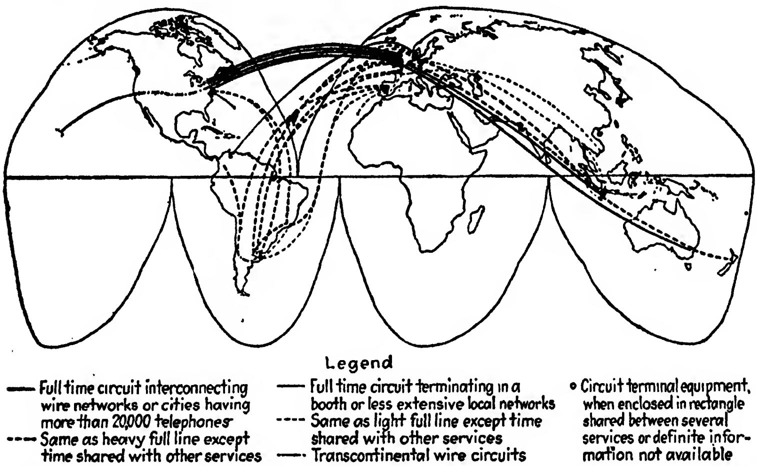


FIG. 40.—International telephone circuits of the world (1932). Solid lines are full-time circuits; dotted lines, shared with other services.

ing prodigiously. Long-distance service has not only improved greatly in the past 5 years, but the rates have been substantially reduced. More than half the telephones of the world are in the United States, and 85 per cent of the world's telephones can be reached from any Bell System telephone. This is indeed a wonderful achievement.

The most spectacular achievement perhaps is the two-

way transatlantic service inaugurated in 1927. The transmission across the ocean is by short-wave radio, although the local transmitter and receiver which the patrons use are of the ordinary telephone type. International telephony gives promise of extensive growth.

Radio. Private communication from person to person was the original conception of radio, and developments have progressed in this direction with devices for securing secrecy. However, about 1920, the real field of radio was recognized to be general communication to any and all who cared to listen. In that year, the first broadcasting station was built, and now a large portion of the civilized world may listen to the same speeches and musical programs as if the hearers were gathered in one room. The radio enables the President of the United States to sit down and discuss questions of national policy not in a cold impersonal pronouncement but in living friendly speech at the fireside of nearly every home in America. Much of the recent improvement in radio lies in the acoustics of the loud speakers as well as in the transmitting and receiving apparatus. Midget microphones which can be placed in the coat pocket or attached to the coat lapel of a public speaker greatly add to the convenience of broadcasting. The installation at Los Angeles, an example of large installation, consists of antennas on 400-ft. towers insulated from the ground. The future developments in radio are unpredictable. By means of the amplifying tube, the volume of speech can be multiplied billions of billions of times. Frequency modulation has been introduced to eliminate static and other stray noise interference. Radio in train control and in the operation of police cars is developing rapidly. Radio-telephone service offers expanding possibilities.

Remote Control. In recent years, electric substations and electric-motor installations are being placed under the control of operators at distant stations, thus saving the cost of local attendance. Electrical devices, circuit breakers, and automatic switch gear are made so sensitive to changing load and other conditions that an attendant is unnecessary. Telemeters permit the reading of instruments at a distance as well as at the site.

Various devices for the guidance of airplanes by electromagnetic waves have been developed in recent years, and the magneto compass brings to aviation a reliable guide as to directions, even when vision is impossible.

Photoelectric Cell. The photoelectric cell (the "electric eye") is a vacuum or a gas-filled tube coated over the inside with a light-sensitive material, like potassium bichloride or cesium oxide-silver, which is connected to one terminal of the cell. When changes in the light intensity on such a cell occur, electrons are emitted or electromagnetic waves are set up in proportion to the intensity of the light, which can be amplified and transmitted either over a wire or through space or utilized in numerous other ways.

Photoelectric cells are so sensitive to light that they may be used to control electric devices for doing various operations such as stopping and starting machines and sorting articles of different colors. For example, such a device is used for sorting beans. If beans are passed before a photoelectric cell, brown or otherwise discolored beans will so affect the photoelectric cell that it instantly operates a device to reject them. The invention of the photoelectric cell, which virtually converts variations in lights waves into electromagnetic impulses, offers to the electrical engineer a device of great possibilities.

Television. Recent developments in television include receiving sets which yield larger and clearer pictures on a screen of surface-treated plastics, an optical system of mirrors and lenses which collects from the receiving tube and projects on the screen much more light than heretofore, a frequency control which eliminates interference from stray signals and thereby minimizes picture distortion, and a high-voltage tube which improves the initial image. Stations for national hookups are yet to be established. Transmission of pictures through telephone cables has been proved practical. Television is synchronized with radio so that vision and voice can be received simultaneously.

By *telephoto*, pictures are transmitted any distance, making views of world-wide events to appear in the morning newspaper. By *facsimile*, special news broadcasts including pictures received by the home radio during the night can be recorded and read the next morning.

Electronic Tubes. DeForest's discovery of the thermionic or radio tube stimulated a flood of investigation in vacuum and gas-filled tubes which resulted in the development of a number of "electronic tubes." Fluorescent lights and photoelectric cells are examples. Instruments employing electronic tubes can measure the electric impulse of a heartbeat and can distinguish more than 2 million shades of color, whereas the natural eye can distinguish but a few hundred. The electron microscope magnifies many thousandfold; the electron analyzer will select a particle a millionth of a milligram in size; an amplifier can magnify murmurs inaudible to the ear into a roar; doors open as one approaches; dust is precipitated from the air; and many other applications are being made.

An electronic tube is essentially a valve that controls the flow of electricity in a circuit. It may contain a vacuum, or it may be gas filled. The former acts like a throttle for varying the flow, while the latter is more like a switch for stopping and stopping the flow. It consists of four essential elements: (1) a cathode for giving off

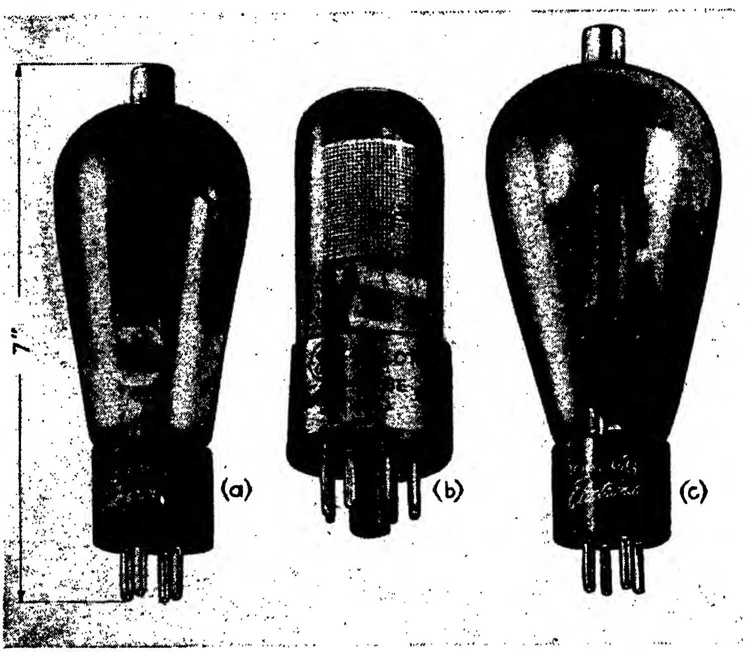


FIG. 41.—Electronic tubes. (*a*) Thyratron; (*b*) radio receiving tube; (*c*) phanotron. (*Courtesy of the General Electric Company.*)

electrons, (2) an anode for receiving electrons, (3) a glass or metal envelope (the tube), and (4) the terminals for connecting it in the circuit; in some forms it has a fifth element (5) the grid that controls the flow of electrons. Current passes through it only by means of the stream of electrons flowing across the gap between cathode and anode, where it is highly sensitive to control.

Electronic tubes have been given various names, such as *kenotron* for supplying direct current at high voltage, the *phanotron* to supply direct current for intermediate loads, the *ignitron* for heavy duty, the *thyratron* for timing heavy currents, the *pliotron* for heating, and the *pentode* for a general-purpose amplifier. Figure 41 shows three typical electronic tubes. The control of electric energy afforded by electronic tubes magnifies the field of the electrical engineer.

Electric Sounding. In recent years, electrical methods for sounding the depth of the ocean or other body of water, by means of timing sound waves reflected from the bottom, have been extensively used; and similar devices are used for sounding the depths to rock under the earth's surface and to oil formations. The sonic altimeter gives the aviator reliable information as to his height above ground by means of timing the return of sound waves sent from the airship and reflected from the ground.

Timing the return of electrical signals by means of electronic recording has been used extensively for military observations. This process is called *radar*. By this means, the distance to ships, airplanes, and other targets can be ascertained with sufficient accuracy to direct gunfire. In peacetime it will prevent collisions of ships with each other and with icebergs, promote the safety of aviation, and have many other applications.

CHAPTER XV

ACHIEVEMENTS IN MECHANICAL ENGINEERING

Steam Turbines. The steam turbine has developed to such superior efficiency and economy that the reciprocating steam engine has become nearly obsolete for steam power generation in large stationary plants. Speed of

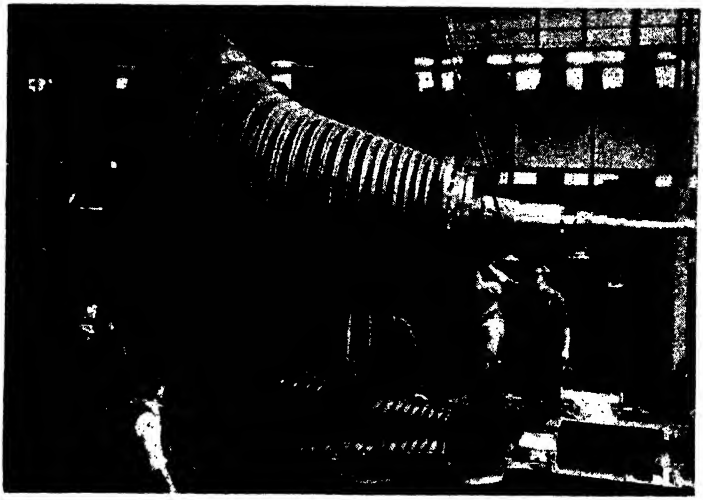


FIG. 42.—Modern steam turbine. Placing the rotor of a 60,000-kw. turbine in its cylinder.

operation for large units has increased from 750 to 1,800 and 3,600 r.p.m. Turbines of about 200,000 hp. have been built and turbines of 360,000 hp. have been proposed. Steam at 1,200 lb. per square inch and at even higher pressures is now being used, whereas, until recently, pressure of 200 lb. was considered the upper

limit. The machining of the intricate parts of a huge steam turbine and the procedures in reducing strains in manufacture are achievements which match the scientific knowledge of the properties of steam underlying the design. Figure 42 shows a modern steam-turbine rotor or spindle being lowered into its cylinder.

Power Plants. Developments in electric transmission of power have caused the steam power plants to be located at advantageous points with respect to fuel and water and to be built of large size. Typical of such practice is the State Line Plant (Illinois-Indiana) south of Chicago, which will ultimately have a capacity of 1,000,000 kw.

The first unit of 208,000 kw. consists of six boilers which furnish steam at 600 lb. per square inch and 750°F., and three turbines on the generator shaft, a 76,000-kw. high-pressure turbine with a 62,000-kw. low-pressure turbine on each side. The plant furnishes about 1 kw.-hr. (energy to operate 25 ordinary 40-watt lamps 1 hr.) for every pound of coal burned.

The second section, consisting of one 150,000-kw. and one 125,000-kw. unit recently installed, is using steam at 1,200 lb. pressure and 825°F. temperature.

The boiler equipment and facilities for handling the coal and ashes constitute vast engineering problems in themselves. Figure 43 shows the coal-handling crane and crusher and the automatic-stoker room of a modern power plant.

Coal Utilization. The coal consumed in the United States amounts to about 70 million tons of anthracite and 700 million tons of bituminous coal annually. About 350 million tons of coal are used for power production, 230 million tons exclusive of railroads and shipping. The average rate of power production is about 2 lb. of

coal per horsepower-hour, the better plants at 0.65 lb. and the poorest at 10 lb.

The automatic chain-grate stoker for large boilers gave the first marked economy in coal utilization which was

FIG. 43.—Coal and boiler installation. Automatic stoker room for a large power plant. Cranes load the coal in the crusher above from which it flows to the bunker (not shown) and thence down the spouts to the stokers.

increased by underfeed and further improvements in the stokers. More recently, dry powdered coal blown into the furnace having water-cooled walls has given even greater efficiency.

Smoke and dust nuisance has almost entirely been eliminated in the better plants through more complete combustion of the coal.

Hydraulic Turbines and Pumps. Marked improvement in hydraulic turbines for water power has been achieved in recent years. The 10,000-hp. turbines at

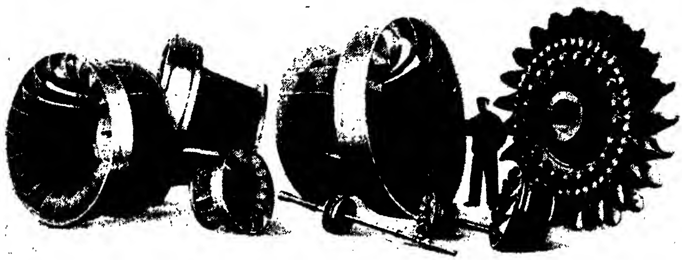


FIG. 44.—Hydraulic turbines. These wheels are for heads varying from 8 to 2,000 ft. The impulse wheel for the latter is at the right.

Keokuk under 32-ft. head were the beginning of this new development of more efficient turbines, and the 54,000-hp. turbines of the Conowingo plant operating under 89-ft. head represent the recent advance. Turbines of similar type are also now used for high heads of 800 ft. or more. Recent turbines have an efficiency over 90 per cent.

Along with turbines, centrifugal pumps (somewhat similar in design to turbines) have made progress and are used for either small quantities at high head (up to 400 ft.) or large quantities at low head (*e.g.*, 100,000 gal. per minute at 28-ft. head). Figure 44 shows a group of water-turbine wheels and an impulse wheel (driven by a jet against the vanes) on the right.

Internal-combustion Engines. Internal-combustion engines may explode gasoline, gas, or heavier oils in the

cylinders to produce the heated expansive gas for pushing the pistons. The gasoline engine, because of the great diversity, its applicability and its lightness, has had a marked influence in some fields. It has made possible the modern automobile, the airplane, the motorboat, and the small independent power plant. The modern airplane engine produces 1 hp. for each 2 lb. of its own weight, contrasted with about 20 lb. in early planes. A small gasoline engine can now be purchased for $50 which would have cost $1,000 in the earlier days of development.

The more recently introduced Diesel engine, similar in principle to the gasoline engine but operating at high compression on oils heavier than gasoline, has had a marked influence. It is being used widely in smaller isolated plants and is finding a place in power for transportation.

Conveyors and Elevators. The handling of materials both on the level and through a vertical distance has always been a major problem for mankind. Pneumatic carriers, belt and chain conveyors, grab buckets, live rolls, derricks, cranes, dump cars, trucks, and earth-moving equipment have all but eliminated human labor from this arduous work. Also elevators for grain and other similar materials have brought a corresponding benefit.

Elevators for tall buildings have almost the character of vertical railroads with their local and express service. Speeds up to 12 or 15 m.p.h. are now used with the improved emergency stop devices. Formerly, the rails or guides were attached rigidly to the building and therefore caused trouble by bending with the deflection of the structure under loads and temperature changes. Now they are attached flexibly so that the guides remain straight regardless of building movement.

Automatic stops, both regular and emergency, have added greatly to the convenience of elevator service.

Automotive Vehicles. The requirements for strength in materials in automobiles have greatly stimulated the development of alloy steels and the treatment of steels to yield greater reliability. Steel for piston and connecting rods, for axles and transmission, has had to meet tests of unprecedented severity. The modern automobile in speed, reliability, and ease of handling is a creditable achievement of mechanical engineering.

Perhaps no other product of engineering has come so quickly to a high degree of perfection in all details as the automobile. Engine, transmission gear, oiling system, electrical distribution, bearings, guiding mechanism, tires, and paint have developed with phenomenal rapidity from their crude beginnings to a remarkable degree of perfection.

The outstanding achievement in automobile manufacture is the mass production, which has decreased the cost of production to the point where luxury characterizes the cheaper cars and where there are now nearly as many cars in the United States as there are families.

Aeronautics. The development of the airplane has been based largely on the science of *aeronautics,* which means literally "air-sailing science" and includes *aerodynamics,* or the mechanics of air action. This science has been advanced by theoretical analyses, by laboratory investigations in wind tunnels, and by practical observation in flight. Air blown against the airplane model in the wind tunnel has the same behavior as when the airplane is flown against the air at the same velocity. The Wright brothers built the first wind tunnel, which was 16 in. square and 8 ft. long. In contrast, the tunnel at Ames Laboratory at Moffett Field, Calif., is 172 ft.

wide and 132 ft. high. A test plane can be "flown" in this tunnel with the engines running and the pilot at the controls. To produce a wind velocity of 200 m.p.h. in this tunnel requires 24,000 hp.

The science of aerodynamics is also involved in the streamlining of automobiles, railway coaches, aerial bombs, and other projectiles. One of its chief applications relates to the airplane propeller. The lift of an airfoil results from giving it a shape to produce an ideal flow of air around its surfaces. The science of aeronautics is now highly developed, and working data are completely tabulated.

Airplanes. The airplane is one of the notable achievements of mechanical engineering in the past half century. Its development has been greatly accelerated by the exigencies of military service, but the commercial utilization of those advances seems realizable in an epochal future for the airplane.

Building an engine of minimum weight for the required power and a light strong fuselage are problems of design quite as much as the aerodynamic shaping of the airfoils. Using a noncorroding metal that does not require paint saves about 100 lb. of weight and reduces the air resistance of flight.

The development of instruments for navigating the air, keeping on the direction beam, and maintaining radio contact with the ground stations has been as important as the improvement of the aeronautical features. The complexity of the panel board tasks the attention of the pilot.

The Superfortress of the U.S. Army is 141 ft. tip to tip of wings, weighs 20 tons, and can carry 10 tons of bombs. It is composed of 55,000 numbered parts and required some 300 engineers in its design. The new

Boeing stratoliner (Fig. 45) will carry 100 passengers on its two decks, or 35,000 lb. of cargo, at a cruising speed of 340 m.p.h. A 750-passenger airplane with a wing spread of 320 ft. is under construction. A 72½-ton flying boat has been built with a wing spread of 200 ft. and an engine capacity of 8,000 hp.

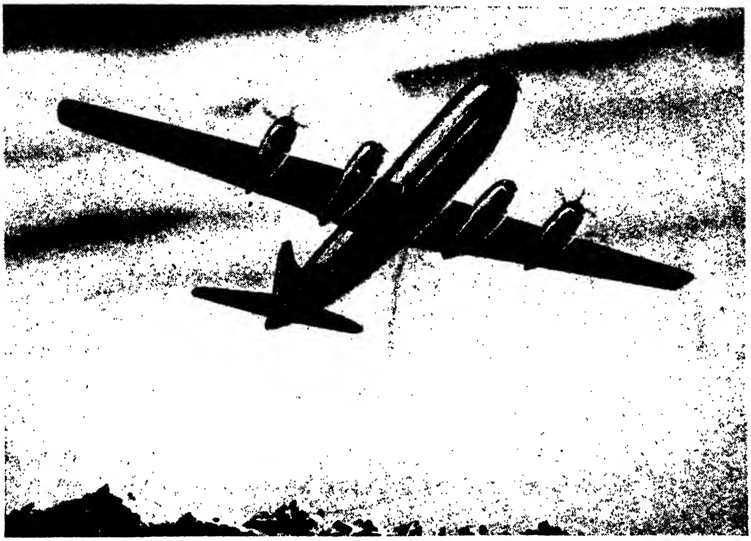


FIG. 45.—Boeing stratocruiser. Two-deck, three-cabin fuselage; 14,000 hp.; top speed 400 m.p.h., cruising speed 340 m.p.h.; pressurized cabin maintains comfortable breathing at 30,000-ft altitude. (*Courtesy of the Boeing Airplane Company.*)

Jet propulsion offers speeds beyond the range of propeller planes, and a light gas turbine has been designed which promises speeds even exceeding those of sound in air. Rocket-assisted take-offs seem likely to reduce the necessary lengths of runways, and reversible propellers give "braked" control in landing.

The *helicopter* has a wide utility owing to its ability to rise and to land vertically and to hover at one point

for observations. Its speed and capacity make its use supplementary to that of the airplane. The *autogyro*, whose motion is determined by shifting the propeller blades, has characteristics similar to those of the helicopter.

The development of the airplane has been dependent on the simultaneous improvement in light metal alloys and their fabrication, refinement in stress analyses, higher octane gasoline, the perfecting of instruments of navigation, and radio control. The entire creation is a marvelous achievement.

Locomotives and Cars. The steam-railway locomotive has been called the most perfect machine yet built by man. From the simple device of flanges for keeping it on the rails to the complicated superheater, compound engines, air brakes, and controls, it is a marvel of efficiency when one consider the conditions under which it operates. A complete power plant, furnishing power, heat, and light, equivalent in capacity to a stationary power plant necessary to furnish electric lights and street-car service to a city of 30,000 population—yet it operates with a high efficiency, notwithstanding it must move along the track at perhaps 30 or 80 m.p.h. The mechanical construction which enables it to pass curves and to run smoothly on the rails is the result of a long evolution. The large freight locomotive for the Northern Pacific Railway recently built, weighing, with tender, over 1,000,000 lb. and having a tractive effort of 140,000 lb., which with the booster can be increased to 153,000 lb. at low speeds, represents recent accomplishment in locomotive building. Figure 46 is a picture of this achievement in locomotive building.

Not only locomotives but the safe steel passenger coaches and the variety of special-commodity freight

cars, together with the work equipment, represent the achievements of mechanical engineering in the railroad field.

More recently, the gasoline locomotive, the gas-electric, and the Diesel engine locomotive are finding a place in railroad operation. Steam-turbine locomotives are being introduced experimentally.

Perhaps the most important single mechanical contribution to railroad operation is the air brake, which

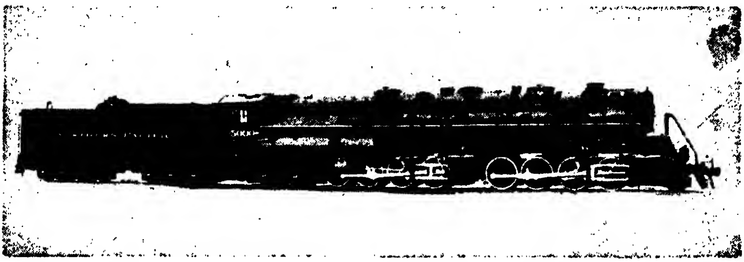


FIG. 46.—Heavy-duty Mallet type locomotive. Boiler pressure, 250 lb.; wheel base of engine and tender, 112 ft.; total weight, 1,118,000 lb.; tractive effort, 140,000 lb.

permits the reliable control of long trains, thus reducing operating costs.

Heating and Ventilating. Heating of homes and larger buildings from one plant has been greatly improved through the introduction of warm-air conduits and controls and the development of hot-water and steam systems.

However, the great improvement in heating procedure is represented by the heating from central stations for all large buildings in a city within a given district. For example, some 2,500 buildings of the new and larger type in the heart of New York City are heated by one steam-heat company. Its power plants are located on the shore with easy access for coal and where least objectionable

to other properties. This company now has about 65 miles of heat mains under the ground of that district covering several square miles. Thus the smoke and dirt from burning great quantities of coal are eliminated, for in this whole district not a chimney is in sight.

Not only heating but systems of air conditioning for humidifying, cooling, and changing air have been installed which greatly improve the comfort and sanitation of large buildings. Office buildings may be kept as comfortable in summer in warm climates as in the choicest seasons of the year. Air conditioning has recently been introduced in railway coaches, thereby greatly adding to the comfort of train travel.

Refrigeration. Developments in refrigeration have not only brought purer ice than the natural ice stored from ponds in winter but has made possible the storage of fresh fruits and vegetables as well as their shipment, so that they are now available all year round. Even ripe fruit can by this means be shipped satisfactorily. Mechanical engineering contributes in these ways to the enjoyment and health of mankind. More recently, the development of low-temperature refrigeration, such as "dry ice" (frozen carbon dioxide), has made some progress, and the use of freezing lockers is expanding.

Machine Work. The achievements in building powerful turbines and engines as well as other huge equipment have been made possible through the wonderful accuracy and capacity of modern lathes, milling machines, planers, grinders, and drills. Figure 47 is a picture of a large crankshaft being machined with the precision of a hair width. This ponderous shaft is carried by cranes and exactly placed for machining. Surfaces of bearings in airplane crankshafts are finished by electronic devices to a few millionths of an inch in smoothness.

Industrial Organization. As manufacturing grew in magnitude, mechanical engineers came to give more attention to the principles of human efficiency and organization, and "industrial management" arose as a semiscience. Frederick W. Taylor, a mechanical engineer of wide experience, made the most profound con-

FIG. 47.—Machining a large crank shaft. Even huge parts are machined with great precision.

tribution by showing that by job analysis and direction of process the output per worker could be greatly increased. The scope has been since enlarged to include economic purchasing on specifications, wage systems, personnel selection, and employee-welfare projects. This aspect of mechanical engineering is sometimes called *industrial engineering.* The marked decrease in production costs as a result of industrial organization is one of the most notable achievements in the field of mechanical engineering.

Automatic Machines. Automatic machines for the manufacture of products varying in size from the tiny parts of a wrist watch up to automobile frames not only have effected great reductions in the price of goods, but have promoted the uniformity of product. A comparison of an old handicraft clock in a museum with a modern watch proclaims the superiority of machine processes as

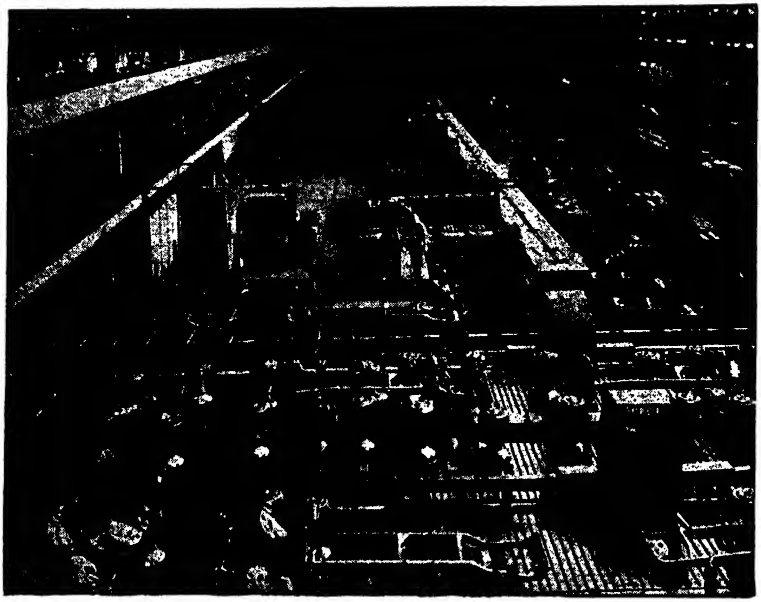


FIG. 48.—Automatic machines in A. O. Smith factory make automobile frames with almost no hand labor.

to reliability. A trainman's watch, for example, is allowed 5 sec. variation a week, which means that, in ticking five times per second, it must not vary more than 25 ticks in 3,024,000 ticks.

As another example a large metropolitan newspaper may be mentioned. After the linotype machines have prepared the type, the rolls of paper are run through the presses, printed as 12-page papers, cut, folded, and

counted, at the prodigious speed of 100,000 per hour with a reliability and uniformity far excelling the old hand-operated presses.

An outstanding achievement in automatic machinery is represented in the A. O. Smith Corporation of Milwaukee, where an automobile assembly plant is capable of producing 10,000 automobile frames in a day with almost no detailed operation by human hands (see Fig. 48).

Automatic packaging and inspecting of small commercial products is a triumph of mechanical engineering. As an illustration, lubricating oil is put in quart paper containers on an assembly line at a rate of more than one per second. Bottled and canned goods are similarly finished, labeled, and packaged by automatic machinery.

CHAPTER XVI

ACHIEVEMENTS IN MINING ENGINEERING AND METALLURGY

Introduction. Mining engineering and metallurgy are grouped together in the present chapter because they have been associated closely in development and in practice, notwithstanding the dissimilarity in their techniques. Especially in the mining of metals do the two fields border each other. Mining engineering has been considered romantic because it has called men into the wild places and to rugged living. The quest for riches, the hazard, and the element of adventure have attracted young men of imagination. Some great metal mines have been veritable labyrinths of rooms and galleries. Perhaps no other branch of the profession so essentially involves world markets, and many notable mining engineers have been world characters.

Mining Engineering. A mining engineer extracts minerals from the earth and places them on the market. A broad preparation is required for his profession because it may involve phases of almost all other branches of engineering plus miscellaneous other knowledge connected with the mineral industries. It requires the science of geology for *prospecting*, *i.e.*, locating ore-bearing strata, petroleum deposits, coal deposits, and other minerals. It necessitates skill in surveying in order to map outcrops of ore or coal, to locate boundaries of mining claims, and to direct and record underground excavations. A mining engineer, as an *assayer*, will

need chemistry to determine the mineral content and value of ores. He may have to lay railroad track for haulage, install hoists and electric lighting, build power plants, erect mine structures as well as smelters and washeries for the treatment of the mine products. Unfortunately the deposits of minerals in the earth cannot be renewed; hence the mining engineer must ever be exploring for new veins. Mining engineering is divided into three fields, *viz.*, (1) metal mining, (2) coal mining, and (3) mining other minerals.

Explorations. In modern practice, mining engineers use geophysical techniques as well as ocular observations in their explorations; they use the ultraviolet lamp to detect the fluorescence of *sheelite*, an ore rich in tungsten; when the radiation from this lamp strikes these tungsten ores, the latter glow fluorescent with variegated colors, which furnish a means of estimating the amount of tungsten present in the veins.

Geophysical methods are also used for locating geological domes and anticlines of sedimentary rock strata below the surface of the earth, the formations in which petroleum is most likely to be found. Sound waves are sent through the earth's outer layers by means of a dynamite explosion or otherwise, and the reflected waves from the rock stratum beneath are detected by delicate instruments at the surface. Knowing the velocity of sound waves through various earth strata and the distance between the point of explosion and the point of detection of wave, the depth to the stratum and its inclination can be computed with fair accuracy.

Ordinary explorations through rock are made by boring with a diamond drill about an inch in diameter, an art which has been highly developed. At McCamey, Tex., a boring was sunk to 12,786 ft. in search of petroleum,

which is perhaps the greatest depth yet reached by drilling. The bottom temperature was recorded as 182° F. The drilling tools at that depth weigh about 150 tons and the casing somewhat more than that figure. Such drilling is an achievement of great skill, and the interpretation of the observations of the material removed necessitates highly expert knowledge of earth formations. Gyroscopic clinometers and specially designed cameras make it possible to obtain information on the strata at great depths from relatively small drill holes.

Coal Mining. Methods for anthracite differ somewhat from those used in bituminous mining, but some general procedures are common to both. In underground mining, the room-and-pillar plan is almost universally employed. The pillars may constitute as much as 50 per cent of the total deposit; although as high as 90 per cent extraction is sometimes attained. The coal is *undercut* at the *breast* of the working, blasted down, and hauled away in mine cars. The *stope* naturally follows the gradient of the vein of coal. A number of special mining machines are in use for undercutting, loading, and other operations which reduce hand labor.

Where the depth of the vein is not too deep beneath the earth surface, coal is mined by *stripping*, *i.e.*, by removing the *overburden* of earth, excavating the coal, and then replacing the earth. Huge power shovels with dippers of 30 cu. yd. or more capacity are used in removing the overburden from a strip and piling it in a ridge at one side.

One of the problems of coal mining is safety from caving of the roof at the breast of the working, and a second is safety from explosions of dust or gas which may burn or suffocate all who are in the mine. Methods

of preventing and combatting such accidents constitute an important phase of mining engineering. The problem is complicated somewhat by the human difficulty of getting compliance with safety measures on the part of the miners involved, who are inclined to be foolhardy at times with regard to the risks. The U.S. Bureau of Mines maintains a staff of specialists on mine safety and has done much to eliminate sources of danger from

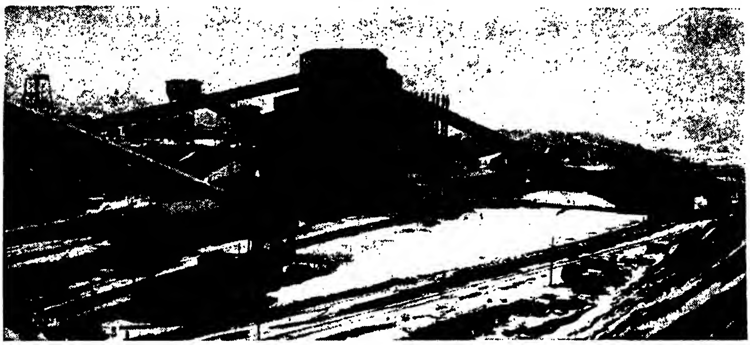


FIG. 49.—Typical anthracite breaker for washing and sizing coal for the market. Culm or waste pile in the background. (*Courtesy of the Hudson Coal Company.*)

improper mine lamps, explosives which produce flame, fuses, and other hazardous practices.

Preparation of Coal for Market. After the coal is mined and brought to the surface, it must be broken to size, screened, washed to remove slate where necessary, graded, and otherwise prepared for the market. Figure 49 shows a view of a "breaker" and "washer" of the Hudson Coal Company at Scranton, Pa., for the preparation of anthracite. Many mining engineers become mine operators or managers, in which capacity their duties pertain to marketing the product quite as much as to mining methods.

Metal Mining. The greater opportunities for metal mining are now to be found in Asia, Africa, and Latin America, although many deposits in North America are still unexhausted. Three types of method are employed, (1) placer, (2) open cut, and (3) underground.

In placer mining, streams of water are played from nozzles, or *monitors*, on the gravelly deposits containing the metal, which *sluice* the material on to beds and screens where the separation is made by differences in gravity.

Open-cut methods (stripping) are conducted by excavating the ore at successive *benches* at the sides of the mine opening, the tracks for haulage being laid on these levels. Iron ore, which usually occurs in huge masses, is commonly mined by this procedure.

The underground opening in which the miners work is called a *stope*, the depth of which depends on the thickness of the vein. The mineral deposit is taken out by "rooms," leaving pillars of the ore stratum to support the roof. Where the quality of the ore warrants the expenditure, these pillars are replaced by piers of concrete or other masonry. The stope follows the vein and may be at any angle from horizontal to vertical. *Top slicing* is used where the vein outcrops, slices about 10 ft. thick being taken out from the top. *Caving* is used mostly in large iron mines and is accomplished by caving the ore down vertical shafts, or "raises," to a haulage tunnel below. Ore is undercut by *drifts* about 25 ft. apart and worked into chutes which carry it to the raises and, thence, to the haulage tracks below.

The deepest mine in the world is said to be the Turf shaft (gold mine) at Johannesburg, South Africa, which in 1934 was 8,400 ft. below ground surface and still going deeper. The temperatures were recorded as

100°F., necessitating the use of cooling devices. Tremendous rock pressures are encountered at that depth.

In all mine operations, water seeps into the openings, often in such large amounts that extensive drainage works are necessary.

The separation of the heavier minerals from the dross of the ore is commonly effected by the *flotation* process, which consists in agitating the finely crushed ore in water with certain additions and producing a froth by blowing air. The froth carries the fine particles of the mineral to the surface, leaving the *gangue* to settle to the bottom.

Assaying. The special chemical analyses used in determining the percentage of metal in the ore is called *assaying*. Gold and silver are usually found together with lead in the same ore and must be separated out by special techniques, consisting of (1) *fusion*, (2) *cupellation*, and (3) *parting*. The ore is fused in a clay crucible with a reducing agent such as charcoal, and when fluid, poured into a mold, where the "button" of metal containing gold, silver, and lead appears. The percentage of each metal is then determined by chemical analyses. A "cupel" is a shallow cup that will absorb the lead when heated very hot, leaving the gold and silver together. The "parting" is accomplished with nitric acid, which will dissolve the silver but not the gold. Other methods are used for assaying ores of copper, lead, zinc, iron, and other metals.

Mine Appraisal. A mining engineer is frequently called upon to determine the value of a mine property including the mineral deposits not yet removed. He can estimate the cost of construction of all structures and their accrued depreciation. By studying the geological formations, he can estimate the amount of the ore

or coal yet available in the ground, its cost of mining, and its probable value. In this connection, he must be familiar with mining law in order to know how any conflicting rights may affect the value.

Smelting. The process of extracting metals from their ores is called smelting and is usually accomplished by heating the ores in the presence of a reducing agent such as charcoal, coal, or coke. Since most ores are oxides, their oxygen is given up to the carbon and the metal in molten form sinks to the bottom by gravity where it is drawn out.

Iron is smelted in a *blast furnace* about 75 ft. high in which it is heated in alternate layers with coke and with limestone as a *flux*. The molten iron trickles down to the bottom and is drawn off. It may be molded into "pig iron," or it may be taken in liquid form to be made into steel.

Aluminum is smelted from the ore bauxite, a hydrated aluminum oxide, by heating in an electrolytic furnace after being refined with caustic soda. If other metals are in the ore, they come out with the aluminum and must be separated. Magnesium is extracted from its ore in a similar manner to aluminum.

Copper, zinc, and lead are reduced in much the same manner as iron, after being roasted to remove certain impurities.

Whether smelting lies in the province of the mining engineer or of the metallurgist is a moot question. Many metallurgists devote their attention to the properties and working of the metals after they have been extracted. It is at the smelter that the mining engineer turns the material over to the metallurgist, and since ore, which is within the field of the mining engineer, is not metal until after smelting, we may say for the

present purpose that smelting is a phase of mining engineering.

Much progress has been made in recent years in smelting by means of which lower grade ores can profitably be used. This is important because the deposits of the high-grade ores of most metals are approaching exhaustion.

Nonmetallic Minerals. In addition to the metalliferous ores and coal, there are many mineral industries that fall within the proper province of the mining engineer. These include gypsum and salt mines and quarries of slate, mica, asbestos, building stones, and raw materials for cement and various manufactures. The total mineral industries of the United States in 1942 amounted to about $7.5 billion; metallic, $2.4 billions; fuels, $4.0 billions; and nonmetallic, $1.1 billions.

Metallurgy. Metallurgy is the science relating to the structure of metals and their alloys, their physical properties, and their thermal and mechanical treatment. Metallurgical engineering comprises the devices and procedures for accomplishing metallurgical treatment on a commercial scale. Electrometallurgy is the branch that deals with the use of electric energy in metallurgical processes. Metallurgy is chiefly physical rather than chemical in character, although elementary chemical reactions may be involved. The importance of metallurgy has been greatly increased in recent years by the developments of alloys and by the utilization of new metals. *Metallography* is a branch of metallurgy that pertains to the study of the crystal structure of metals and alloys by means of microscopic examination and photography.

Steel. Cast iron contains 2 to 5 per cent carbon, steel 0.01 to 1.0 per cent, and wrought iron 0.05 to 0.13

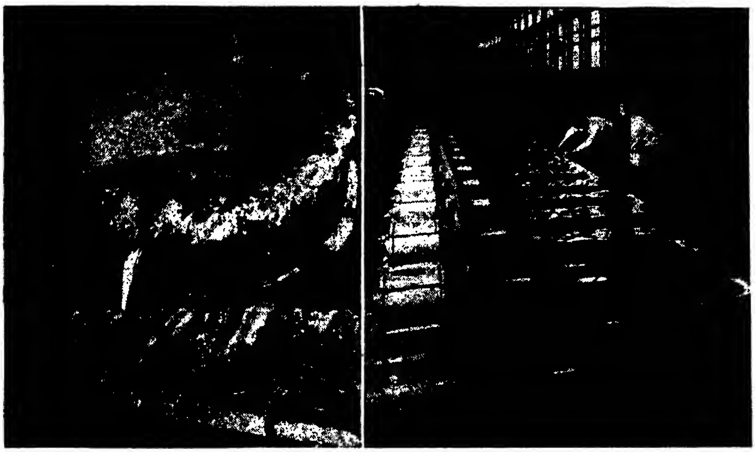
per cent. Steel is composed of crystals of pure iron, of iron carbide (Fe_2C), of carbon, and of other combinations of these elements. Viewed under a microscope, these crystals look somewhat like concrete. The properties of steel depend on the method of treatment in fabrication. The term "heat-treatment" means those processes by which the properties of steel, such as hardening, tempering, annealing, and normalizing, are controlled by heat. The effects are mostly obtained by changes in the crystalline structure and by relieving internal strains resulting from working the metal. With the notable advance in the art of welding steel both by electricity and by the oxyacetylene flame, the effect of heat on physical properties has become of prime importance.

Aluminum. Within recent years, aluminum, which is the most abundant metal in nature, has attained a wide utilization in the manufacture of appliances, for electrical conduction, and to some extent for structural purposes. It has the advantages of being light, strong, weldable, easily machined, and corrosion resistant in the form of certain alloys. Pure aluminum, being soft and ductile, has limited use, but alloyed with magnesium, chromium, and manganese, it is highly adaptable. The alloy with magnesium is especially hard and strong. Aluminum can be molded as cast aluminum, or it can be rolled into plates and shapes. Its use seems destined to expand in the future. Figure 50[1] shows the processes of pouring "pigs" and rolling aluminum into plates.

Copper. Commercial copper contains about 0.3 per cent impurities of various other elements. Except as an electric conductor, copper is used chiefly as an alloy. Brass is an alloy of copper and zinc, while bronze is

[1] Courtesy Aluminum Company of America.

composed of copper and tin, but the proportions vary so that at the dividing line bronzes and brasses are similar. Copper-base alloys are readily machined, and some are resistant to corrosion; they appear on the market under various trade names. *Monel metal*, for example, is a copper-nickel alloy having high strength and resistance to corrosion. When 2 per cent of beryl-



a b

FIG. 50.—Aluminum production. (*a*) Pouring molten aluminum into pig molds; (*b*) rolling long sheets of aluminum. (*Courtesy of the Aluminum Company of America.*)

lium is added to copper, the alloy becomes heat-treatable, stronger and harder than some steel. For making gears and other shock-resisting parts, copper-coated steel powder is passed into molds and heated, a process called "powder metallurgy."

Other Metals. Other metals whose uses have advanced in recent years are nickel, lead, magnesium, chromium, vanadium, tin, zinc, and tungsten. Tungsten is used for electric-light filaments, zinc for galvanizing iron and for die-casting. Tin is highly resistant to

corrosion and is widely used for plating thin iron plates, for cans, as a base for die-casting, and for bearings. The alloys of these metals and of iron are growing so rapidly in importance that their economical utilization has become an essential feature of modern engineering.

Alloys. An alloy steel is one to which another element, usually a metal, has been added in significant percentage. Manganese, nickel, vanadium, molybdenum, chromium, and tungsten form the usual alloys of steel. Stainless steel is an alloy with chromium and nickel; *invar* is an alloy of nickel and steel which varies little in length under changes in temperature. It is used for measuring tapes. Tungsten steel is used to resist corrosion from high temperatures. High-speed cutting steel is an alloy with tungsten, chromium, and cobalt. Alloys have been devised to resist corrosion from caustic liquors, while others retain strength at high temperatures for use in jet propulsion and gas turbines for airplanes. The development of alloys for special uses is one of the notable achievements in metallurgy.

CHAPTER XVII

SOCIAL AND ECONOMIC EFFECTS OF ENGINEERING

Introduction. Engineering activities have had a profound and far-reaching influence on both individual and social life. Organized society is the resultant of complex human forces, both emotional and rational, active and passive, arising on the one hand from the abilities, ambitions, and freedoms of individuals, and on the other from the actions of groups, either in concert politically, or by common impulse and habit. Technological invention and progress thrive under the social system of free enterprise, which rewards individuals for ingenuity, effort, and venture, and are stifled under socialistic government because political bureaus operate routinely at an average level below the heights of individual vision and devotion. Scientific knowledge, a resource of wealth and a bulwark of security, is social in its evolution and applications, but it is advanced by individual effort. Physical environment, so largely the product of technology, tends ever to fashion new customs. Through science, civilization may attain freedom from the past and, in common quests, rise to a more abundant present and to the constantly widening horizons of the future. Hence, the engineer, conscious of the social potency of his creations, should be alert to their human significance in order that his works may be used truly to benefit mankind.

Land Utilization. By replacing natural products with synthetics, by introducing farm machinery, improving fertilizers, and converting produce to a variety of more usable things, engineering has greatly improved land utilization. For example, synthesizing dyestuffs from coal tar has released about 2 million acres formerly devoted to growing madder and indigo, the chief source of natural dyes. This land turned to rice and millet has alleviated the famine conditions in certain Asiatic areas. The introduction of automobiles and tractors reduced the number of farm horses by half (13½ million) and practically eliminated city horses. This permitted the transfer of 4½ million acres of pasture and several million acres of hay fields in the United States to food production. This change, together with improved agriculture, has increased the production of cattle 30 per cent, hogs 15 per cent, sheep 12 per cent, wheat a third, and milk, truck crops, and poultry nearly doubled. Chemistry has multiplied the variety of goods as cereals, fats, sirups, and others from agricultural crops.

The output per farm laborer as a result of farm machinery has increased over 50 per cent. Even in cotton growing where mechanization has been least, the decrease in labor per acre has been 17 per cent, and a successful picker would effect a further reduction. This change has greatly increased the industrial manpower.

Abolition of Slavery. The abolition of human slavery is frequently ascribed by historians entirely to the advance in ethics, moral justice, and humanitarian principles generally. It is a significant fact that neither the great humanitarians of the ancient world nor those of the Middle Ages were greatly concerned about human slavery but accepted it as a social phenomenon.

The steam engine was invented at the close of the

eighteenth century, and the application of mechanical power through machines to the work previously done by hand spread rapidly during the first part of the nineteenth century. Slavery was universally abolished in civilized countries during the middle half of the nineteenth century. While the amelioration of slavery had grown after the Middle Ages, the abolition of slavery was greatly hastened by the growth of factories through the introduction of mechanical power, which so multiplied the productivity of human labor as to render slavery no longer profitable. Slavery was discontinued in the Northern States not because of superior humanitarian principles, but because slave labor was not usable in industry and the introduction of machinery so increased the productivity of more intelligent labor that slavery was unprofitable. It is not too much to say, therefore, that, while slavery was an outmoded economic and social institution and was everywhere growing out of favor, it was the steam engine and laborsaving machines that caused its demise as a world system.

Amount of Power in the United States. The United States leads the world in the amount of machinery and power in use. In fact, the total power developed in the United States about equals that of all the rest of the world combined. Figure 51 shows the growth of power in the United States, its mode of generation, and its industrial distribution. The factories of the United States utilize about 55 million horsepower. The amount of power has increased from about 0.6 hp. per worker in 1860 to about 5.0 hp. in 1930. In addition, locomotives represent 90 million and automotive vehicles 95 million horsepower.

Equivalence of Mechanical Power in Human Labor. While the formal definition of horsepower may be

learned, it is desirable to grasp the meaning of mechanical power in terms of human effort.

When the Mississippi power plant at Keokuk is in normal operation, it yields about 150,000 hp., which is capable of doing twice as much work as all the men in Iowa could do working 8-hr. shifts, day and night.

In the old days of handicraft manufactures, the output per man was limited to the work that he himself could do

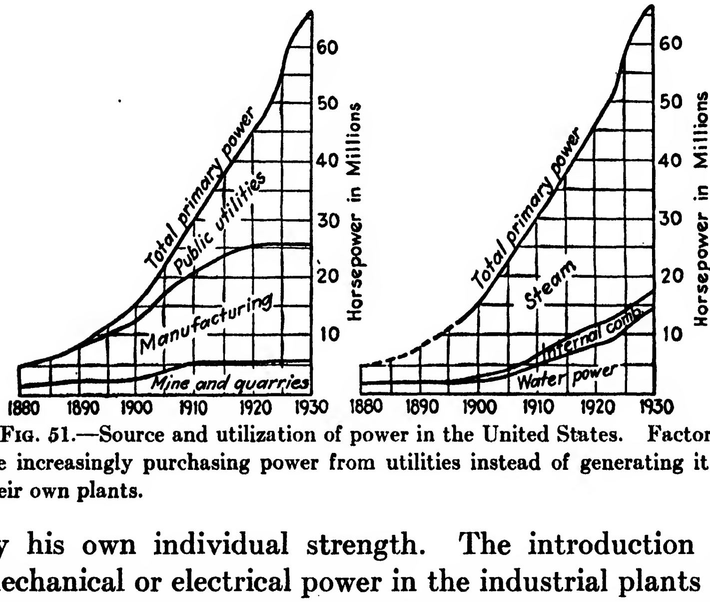


Fig. 51.—Source and utilization of power in the United States. Factories are increasingly purchasing power from utilities instead of generating it in their own plants.

by his own individual strength. The introduction of mechanical or electrical power in the industrial plants to the present extent in America gives each American worker on the average the equivalent of about 60 helpers, so that his output is increased accordingly, with resulting greater profits for the owner and greater wages for the worker.

Shortening Hours of Labor. Before the advent of steam power, men worked 12 to 14 hr. per day in mines and in factories, and children began work at an early age for a mere pittance in order to supply a living for the family. The use of laborsaving machinery has reduced

the day in most places to 8 hr. or less and the week to 5½ days, or perhaps 5 days in the future. This change in the length of working days has resulted chiefly from the use of mechanical power and of laborsaving machinery. While organized labor unions helped, the highly organized unions and guilds that preceded steam had not been able to accomplish much in this direction. Machinery made possible the greater production per man and at the same time required greater alertness on the part of the worker obtained from shorter hours, and the result was the shorter day.

Elimination of Drudgery. The back-breaking toil of building the Pyramids and other ancient structures and the utter prodigality of human labor stands in marked contrast to the present-day mode of work. Even the Lion Mount, constructed on the Field of the Battle of Waterloo to commemorate the fall of a program of selfish personal ambition and national imperialism, at a time of depleted man power following a quarter century of war, was built largely by human labor—for the most part by women—carrying dirt in baskets for about 6 cts. per day. Instead of being beasts of burden, men nowadays have become *machine tenders*, to a great extent, the machines doing the actual work. Conveyors, elevators, dump trucks, dump cars, grab buckets, steam shovels, truck loaders, car unloaders, pneumatic hammers and drills, electric hand saws, and a long list of other devices relieve the grueling toil of former years. The man has virtually become the master of many inanimate slaves who tirelessly do the drudgery.

The firing aisle of a boiler room used to be a hot, grimy, dirty, eye-distressing, forbidding place, where men would singe, sweat, and strain while throwing coal by scoopfuls into the seething maw of the furnace, working

the glowing fire in the blistering glare of the white-hot walls and fuel bed, pulling out great scorching clinkers, and wheeling away barrowfuls of choking, blinding ash.

FIG. 52.—Contrast of man power and machine methods of handling earthwork.

In contrast, the modern boiler room is clean, cool, and comfortable. The fuel is dumped from cars or unloaded from boats by cranes, crushed, elevated, and fired automatically, and the ashes are dumped automatically

and carried away by conveyors or in cars. The only human attendance is chiefly concerned with reading instruments and otherwise observing whether all parts are performing properly—a function of control and manipulation.

Figure 52 gives a contrast between handling earthwork with a steam shovel and by hand methods using men and boys in the Orient.

Effect on Intelligence of Workmen. While in highly organized industry there are many jobs which are so routine that they can be quickly learned and performed without much exercise of intelligence on the part of the worker, most industrial and power operations require a higher degree of intelligence than was necessary in the handicraft stage of industrial development. The significance of the operation, even though simple, in its relation to the entire program, understanding the machinery which he tends, and comprehending the program of coordination and cooperation everywhere about him force complicated mental concepts on the worker and challenge him to master more and more of the process. To quote Fred Low before the World Power Congress, "Brawn has given place to brain, and where only brute strength and physical endurance were required, intelligence finds a market and an opportunity." Electronic controls in the future will largely eliminate the nervous strain of sustained human attention in industry, thereby further elevating the human function to the exercise of rational judgments.

Productivity per Worker. Machines have multiplied the productivity per worker. Before machines, one skilled workman could make 30 needles per day; now a girl attending a machine makes 500,000 needles per day with a resulting decrease in cost. Julius Klein, formerly

Assistant Secretary of Commerce, in a radio talk, gave a vivid picture of the effect of machinery on productivity per worker, as follows:

Probably you have listened, at one time or another, to the chorus of Spinning Maidens which opens the second act of Richard Wagner's opera "The Flying Dutchman." If you have been so fortunate as to see it on the stage, I am sure that you have a vivid recollection of the bevy of flaxen-haired Norse girls sitting at their spinning wheels as they give voice to the sparkling cadence of the song.

"Ah," you say, "those were the good old days—charming, quaint, immensely picturesque." But maybe you wonder a bit about the large number of spinners in the home of one humble sea captain. Your impression may be that this group of 20 girls must be able to spin an enormous amount of yarn.

Let us look at that a moment. Let us take that spinning group and multiply it. Multiply it by a thousand—then double that—raise it to the proportion of a European army corps—pour that vast army of spinning maidens into some outdoor arena like the New York Polo Grounds, filling all the seats—45,000 of them—and then measure the product of their antique spinning wheels during an 8-hr. day.

You will find that they have accomplished no more, with all their spinning, than one girl achieves today with American factory machinery.

That is just one lone example of the miracles wrought by machinery. And the advance of machinery has never been so swift as here in the United States during the decade of the nineteen-twenties. In a Middle Western State there is, today, a huge plant which is filled by what is really a single machine. It turns out completed automobile frames almost untouched by human hands. Each frame remains on the conveyors nine-tenths of the time. To supervise this vast "automat," about 200 men are employed. The plant turns out between 7,000 and 9,000 automobile frames per day. A rather well-known automobile plant in Europe has 200 men in that part of its establishment devoted to this same kind of work. They turn out 35 frames per day. The almost incredible efficiency of our new American machinery could scarcely be illustrated in a more striking fashion.

Many other examples might be cited, but this quotation from Mr. Klein indicates the great increase in productivity per worker effected by power-driven machines.

Relation of Wages to Power Utilization. A study within recent years shows a direct relation between the amount of power used in industry and the rate of wages paid to workers. In fact, the portion of the value of goods that is added by the manufacturing process increases directly with the amount of power used. During the present century the horsepower used in the United States per worker doubled, while value of goods added by manufacture increased nearly fourfold. This increase in the value of goods per worker involved in the process of manufacture is naturally the element that controls the wages of the worker, as well as profit to the manufacturer. It is not surprising to note, therefore, that wages in the United States increased in nearly this same proportion during the period mentioned.

The modern foundry, illustrated in Fig. 53, is a good example of an industrial process in which the output is greatly increased while the drudgery and danger are decreased through the utilization of machinery.

In different countries, also, the value contributed to products by manufacture per worker varies directly with the amount of power per capita used, and wages in those countries vary in about the same manner. The horsepower used in manufactures per capita in various countries decreases from the highest amount in America to the lowest in India and China; production descends in about the same scale. Also, wages are highest in automobile factories, which are the most highly mechanized.

Wages range from the lowest in China and India in about the foregoing order up to the highest as found in the United States. Wages are always highest in mechanized industries, and the mechanization of an industry has always been accompanied by advances in wages. We may conclude therefore, that the utilization of mechanical power in industry tends to advance wages.

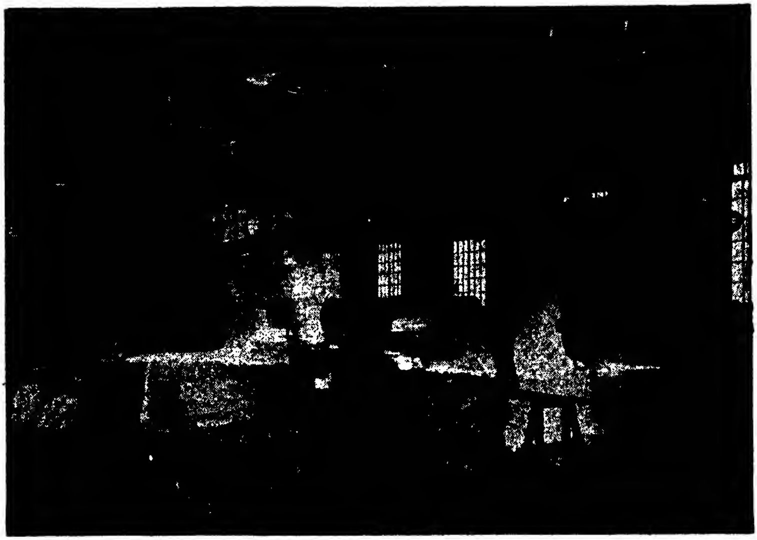


FIG. 53.—The modern foundry. By means of machinery, the output is increased while drudgery and danger are decreased.

Effect of Power on Employment. While the introduction of laborsaving machines causes a decrease in the number of men required to do the particular work involved, such machinery almost inevitably expands work in other ways, by creating new industries. For example, while automobiles displaced the village blacksmith and the horseshoer, they brought work in garages and filling stations. The introduction of the sewing machine when first invented was vigorously opposed by the tailors' guilds whose members feared unemployment therefrom,

yet its use caused more to be employed in the garment industry than before, owing to the fact that better and cheaper clothes multiplied the demand. In fact, in 1929, a high point of mechanized industry, there were more people employed per thousand population in the United States than ever before. Machines created about 20 per cent more jobs between 1920 and 1930 than they discontinued. The invention of textile machinery created 50 per cent more jobs in England than it destroyed, and similar results occurred in printing and in other industries. Hence the introduction of machines does not decrease the total amount of employment, although machines may compel a shift to other employment on the part of individuals.

The effect of laborsaving machinery is, therefore, first, to cause a shift to other employment and, second, to diminish the drudgery type of human labor required to do the world's work with a consequent increase in the productivity per worker and a resulting higher wage rate.

Unfortunately, when the introduction of machinery compels men to shift to other work, this shifting frequently involves individual hardship, and easing this adjustment is one of the foremost problems of modern industry. It is a problem that has been present in essence from the time that even the most elementary tools and machines were first invented and put to use.

Effect of Power on Wealth Distribution. Previous to the advent of mechanical power, the wealthy class comprised landowners, money lenders, and merchants. Power and large-scale industry brought a fourth group, *viz.*, industrialists or manufacturers, which has been even more influential in many respects than all the other groups combined.

A more humane distribution of wealth has been effected through the greater production of power industry. The higher wages have made it possible for workingmen to own their own homes and to accumulate something for failing years. Multiplied wealth has given rise to greater private and public charities for the care of the unfortunate and the incompetent, and has also made possible fair security against sickness, unemployment, and old age, either as pensions from industry or as allowances from public taxes.

Large-scale industry demands selected ability in managerial positions and thereby opens opportunities to technically trained men. Under the condition of small-scale industry of a half century ago, single ownership, which usually amounted to family ownership, filled positions of management only with owners and members of the owner's family and practically barred meritorious men without such family relationship from executive positions. The large modern industry, with its stock widely distributed, opens the way for those of ability and character, who may have neither wealth nor family connection to aid them, to rise to positions of great responsibility. Presidents and other corporation executives in industry are more and more selected from employees who have shown their capacity rather than from among the heaviest stockholders. Large-scale industry brings encouraging opportunities to the capable quite as much as, or even more than, did small-scale industry.

Effect on Health. It has already been pointed out that the great achievement of sanitary engineering lies in the decrease in water-borne communicable diseases, such as cholera and typhoid fever. In the developed

regions of the tropics where these scourges were once rampant, health and prosperity now abound.

Ventilation and light in factory buildings have done much to eliminate industrial diseases. Safety devices on machinery have greatly reduced industrial accidents which formerly mained and killed thousands of workers. The automatic car coupler reduced accidents to railroad trainmen 75 per cent, and other inventions have had similar effects.

The convenience of household bathing facilities through modern water supplies adds appreciably to health and to the comfort and enjoyment of life. Modern sewerage, which removes wastes and reduces them to harmless soil, also contributes potently to public health. These engineering achievements have cooperated with medical advances to improve health. The death rate in London under handicraft industry 200 years ago was 50 per thousand annually, while in the engineering age at present it is only 12 per thousand. Life-insurance records show the present death rate in the United States to be the lowest in history.

Relation of Power to Growth of Population. The population of the world has doubled and that of the United States has increased forty times since the year that Watt invented the steam engine, and the question naturally arises as to the relationship of the two occurrences. The introduction of power, making possible rapid transportation of persons, commodities, and foods, has so increased the possibilities of density of population in cities and so opened arid and other regions to habitation that the growth in the past century and a half has equaled the increase in all the hundreds of centuries preceding.

Of course, increased longevity owing to more effective medical service has contributed also to this end, but improved transportation, storage of foods, city water supplies, and sewage have made it possible for the large population to live on the earth. Increased productivity of soil and of mines has also had an influence, but this in turn is largely the result of mechanical power and machines.

Mass Production Brings Luxuries to All. The drastic decrease in production costs has brought within the reach of all but the very poorest people the conveniences of living which were formerly considered luxuries. Improved kitchen and other household utensils and furniture, tools, better houses, lighting, automobiles, radios, and well-made clothing have been made available at low price as a result of mass production. Bathtubs, electric lights, telephone, and plumbing are enjoyed by nearly all within the cities, and farmers can purchase gasoline engines or electric power directly to do much of the routine work and to furnish many of the comforts which were, until very recently, to be had only in the cities. All these have been made readily available at low price through mechanical power and mass production. One has merely to visit a poorer region of a European country, where living conditions have not been greatly changed in the past century, to observe the benefits of these innovations.

Shifts in Population. The introduction of the automobile has enlarged the radius of the rural patronage of cities so that the village stores have been compelled to close and village churches and schools have dwindled. It is less effort to travel 25 miles now to buy supplies or to market farm produce than it was to drive 3 miles with horse-drawn vehicles over earth roads a quarter

century ago. The result has been the decadence of the villages and the growth of the cities.

Theaters and other amusements are available to rural dwellers as well as to city dwellers. The result has been a tendency to obliterate the differences in the characteristics of city dwellers and rural.

Possibly these results are detrimental in some respects as well as advantageous in others; no attempt is here made to appraise their merits, but merely to call attention to the change and to the causes.

Growth of Large Organizations. A characteristic of the present century has been the appearance and growth of large commercial and industrial organizations. The most potent influence in causing this development has been the telephone, which permits instant communication among officials, even though located some distance apart. Corporations have been organized with offices in practically every large city in America and many in foreign lands. These replace the old-fashioned partnership or small corporation whose officers and directors could meet for conference on an hour's call and whose business relations were largely local.

Chain businesses are to a considerable extent made possible by quick communication and rapid transportation which make possible centralized storage and the operation of the group from one management much as one local business occupying several rooms in the same building. These changes are, therefore, largely the result of engineering achievements.

Railroads and Distribution of Population. Until the railroads were introduced, the United States comprised the states east of the Mississippi, with a vast undeveloped territory to the west. The coast states were prosperous, being active in industry and shipping, but the region

west of the Alleghenies was largely a wilderness in the process of being reduced to cultivation.

The railroads brought a marvelous change. The population began to spread rapidly westward, and the planting of factories and growth of industries followed immediately. The completion of the Union Pacific in 1869 joined the Pacific and the Atlantic, and soon a network of railroads bound the entire country firmly into one united economic whole with a population spread according to economic opportunities.

Engineering Gave Rise to Large Cities. Until the beginning of the machine or power age, cities remained relatively small. In 1800, following the invention of the steam engine a quarter century previously, even the great cities of the world served local communities chiefly, contributing to the national economy only in a limited way, mostly political. The introduction of power-driven machinery greatly diversified and increased manufactures, thereby making a need for more workers in the cities and at the same time diminishing the work in rural areas necessary to produce the food supply and, consequently, the need for workers in rural regions. At the same time, other engineering achievements of housing, water supply, sewerage, transportation, and communication made it not only possible but actually attractive to live in the cities.

As a result, Greater London, which had accumulated 1 million population through the centuries previous to 1800 now numbers 8½ millions; Paris, a very old city, had ½ million in 1800 and now has nearly 3 millions; Greater New York grew in the same time from a group of local trading posts totaling less than 50,000 to a great metropolitan district of 8 millions; Chicago, unborn in 1800, in this time and under similar economic influences

became a city of 4 millions and the greatest railroad center of the world.

Engineering activities therefore, gave rise to the industrial and commercial conditions which caused a concentration of population in large cities and, at the same time, wrought such changes in the physical conditions of city life that such concentration of life in cities was both possible and attractive. Large cities, consequently, may be considered to be, in part, a product of engineering achievements.

Engineering Makes Universal Education Feasible. The elimination of drudgery and of child labor, together with the increased productivity and wages of the parent, which resulted directly from the use of power machinery, has released children from the toil necessary to support the family, both to enter school and to remain in school a sufficient period to permit them to secure a moderate education. Also, the increased earnings per worker through the use of power make it possible for the father of a family to supply his children not only with a living but with school costs, during their school years.

Before the machine age, children even less than five years old worked in the mines, and women worked to the extent of their endurance. L. P. Alford[1] gives the following abstract from an investigation by a Committee of the British Parliament, which furnishes an arresting picture of the premachine age life for millworkers:

[Samuel Coulson, a father of certain working girls is testifying.]

Question: At what time in the morning, in the brisk time, did those girls go to work?

Answer: In the brisk time, for about six weeks, they have gone at three o'clock in the morning and ended at ten, or nearly half-past, at night.

[1] "Laws of Management," p. 198.

Question: Had you not great difficulty in awakening your children at that excessive hour?

Answer: Yes, in the early time, we had to take them up asleep and shake them when we got them on the floor to dress them, before we could get them off to their work; but not so in the common hours.

Question: What was the length of time they could be in bed during those hours?

Answer: It was near eleven o'clock before we could get them into bed after getting a little victuals. . . .

Question: Were the children excessively fatigued by this labor?

Answer: Many times; we have cried often when we have given them the little victualing that we had to give them; we had to shake them and they have fallen asleep with the victuals in their mouths many a time.

While there are some who lament the coming of the machine age, yet its coming has removed such little children from the cruel grind of the mine, mill, and factory and put them in school with decent clothes and adequate food. Engineering achievements, therefore, have brought about conditions which make universal education possible.

Indeed, a small exercise of the imagination may perhaps foresee a time when, because of modern production methods which increase productivity per worker, all educable children can be spared from industry and will remain in school through high school or even through college. The fact that the proportion going to high school and college in America has about quadrupled within the present century has such a significance.

Political Results of Engineering Achievement. The steam engine was developed in an effort to pump water from the coal mines in England when horsepower was proving inadequate to this task. The success of the steam engine made England an industrial nation and a first-rate world power.

The gradual dying out of sectionalism in the United States is largely the result of the moving about through improved transportation, acquaintance through better communication and through cheap newspapers from the power presses. Fortunate it was that the age of mechanical power was ushered in with the birth of this nation, for otherwise the quarreling, jealous colonies would not have become so closely associated as to make the great Federal government under the Constitution a working reality. Dissension amongst small states in other parts of the world is greatest where means of travel, trade, and communication are most primitive. It is not too much to say, therefore, that the Federal success of the United States is in a measure the result of engineering achievements. Further, through instantaneous broadcasts, permitting truth to anticipate hysteria, they may yield that sane public opinion so essential to representative democracy. Technology has necessitated the expansion of governmental bureaus and has outmoded slow-moving governmental machinery in coping with resultant economic complexities. By spreading business agencies countrywide, it has compelled national regulation, thereby enhancing Federal at the expense of state government. It has strained the constitution at many points, as for example, the overworked interstate-commerce clause. It has implemented political ideology with tremendous power, thereby multiplying the responsibility for justice. If statecraft should adopt scientific detachment in its findings and streamline its administration for efficiency it could more adequately surmount the social forces and velocities of a technologic age.

Effect on International Relations. Of the four great scourges of the human race in the evolution of civilization, *viz.*, famine, pestilence, natural elements, and war,

science has nearly abolished the first three in enlightened countries, and now bids fair to effect the abolition of the fourth, *i.e.*, cataclysms in international relations.

Through modern transportation and communication, the world has become virtually a neighborhood, necessitating more intimate acquaintance and greater tolerance. Since a conflict now may embroil the entire community, the world must be organized and policed indivisibly. The facilities that permit heads of states to confer in person and to communicate instantly and news to be broadcast to all peoples make such coordination possible. Through the devastation from technologic devices, war may have wrought its own obsolescence by transcending the nerve endurance of human beings and the economic capacity of peoples. The mechanization of warfare has increased its monetary cost a millionfold per man killed since the days of sword and spear, and no possible booty can be commensurate with the outlay. No one escapes its calamity. Victory is now decided more by resources and industrial production than by commander's strategy or soldiers' bravery. Through technology, war has lost its epic glamor and become a drab loathsome efficiency in destruction and slaughter. Gas, rockets, incendiaries, and airplanes, overleaping all defensive barriers, may have conquered even war itself.

Other means of attaining national wealth and prestige have beome available through science. Chemistry can yield synthetic and substitute materials to render nations more nearly self-sufficient. Because industries based on the new technology will yield without waste more wealth than will conquest with destruction, and because the fruits of scientific exploration justly accrue in proportion to the intelligence and virtue of peoples,

equally in small countries and in great, enlightened nations, which are politically mature rather than tribal or feudal, will see in the frontiers of science their national hopes and will more and more supplant war with research as an instrument of policy.

Since wars result more from political maneuvering than from popular will, in a scientific world where peoples have intercourse with other peoples by groups independently of political channels, international relations are being spread on a widening front so that the destinies of nations will be less subject to the human frailties of their foreign offices. The motto of the British Broadcasting Corporation is "Nation shall speak peace unto nation," and through international radio peoples will converse with peoples and understand. Science, like a benign spirit, passes political boundaries. In a one world of electric waves, the traditional ideology of isolation, kingly sovereignty, and war are tending to yield to a universal seamless fabric of scientific, industrial, commercial, professional, and labor organizations with each group effecting its own international accommodations. Through radio, motion pictures, and microfilm, education is progressing toward an international office for a world view of historic and anthropologic truth. These technologic factors are operating to force political concepts out of the vestigial patterns of chieftains and depredations into a universality matching science and humanity.

Social Responsibility of the Engineer. Engineering *makes possible* great social benefits, but it does not *ensure* them. Whether these social benefits are realized or not depends upon the objectives and the spiritual motives of engineering effort, on the one hand, and the ability of the public to recast the social, economic, and

political institutions in terms of engineering achievement, on the other.

To incorporate successfully these profound and far-reaching results of engineering operations into modern affairs, social institutions must be adjusted to provide for the greater leisure of laboring men and to distribute the fruits of industry so that leisure may be a benefit rather than an injury. Actual technological unemployment must be avoided through the economies of the innovations, and violent industrial booms and depressions must be overcome through controlling financial arrangements and through modulating reservoirs of construction and industrial activity.

As a citizen, the engineer must share the responsibility for remodeling legal and economic institutions necessary to adjust society to the innovations which his genius has done so much to produce. Many social and economic institutions are predicated on feudalism, the commodity theory of labor, and a local viewpoint and, hence, require revision. A more highly organized society rather than a more simple one seems to be the destined way. Political socialism seems to have been tried (many times) and found wanting. The organization to which the engineer should look, therefore, should be largely economic rather than political, with a governmental protection of individual rights. Moreover, executive positions in government are more frequently being filled by engineers. It behooves the young engineer to devote his thought, therefore, to the obligations of citizenship in order that he may contribute creditably to the common weal under the conditions existing in the power and scientific age.

APPENDIX

PROBLEMS

General for All Engineers

1. If a 5-ft. post casts a shadow 3.5 ft. long, how high is a tower that cast a shadow 45 ft. long at the same time?

2. If a steel tape is actually 100.01 ft. long because of temperature expansion, and a mile distance is measured off with it without taking into account the error in length of tape, what is the actual distance measured?

3. A standpipe 50 ft. high is full of water. If water weighs 62.3 lb. per cubic foot, what will be the pressure per square inch on the bottom?

4. If a horse weighing 1,500 lb. pulls with a force equal to one-tenth his weight, how many foot-pounds of work does he do per mile? How many per minute if he walks at $2\frac{1}{2}$ miles per hour? This is 1 hp.

5. The strength of a beam of rectangular cross section varies as the width and as the square of the depth. How does the strength of an 8- by 16-in. beam compare with the strength of a 6- by 12-in. beam of the same length?

6. The stiffness of a rectangular beam varies as the width and as the cube of the depth. How does the stiffness of the first beam compare with that of the second?

7. The pressure of a gas varies inversely with the volume if the temperature is kept constant. If gas in a 900-cu. ft. container exerts a pressure of 15 lb. per square inch, what will be the pressure if the volume is increased to 1,200 cu. ft.?

8. What will be the size of a water main required to carry the same amount of water per second as two 6-in. mains, the velocities being the same in the two cases?

9. A tank 20 ft. in diameter and 10 ft. deep has sides and bottom of $\frac{1}{2}$-in. steel plates. If $\frac{1}{2}$-in. plate weighs 1.70 lb. per square foot, what is the cost of the tank at 6 ct. per pound, assuming the rivets and lap at joints to add 5 per cent of weight.

10. If crushed stone contains 40 per cent voids, how many cubic yards of crushed stone will 12 cu. yd. of solid stone yield?

11. The cylinder of a piston pump with 15-in. stroke is 10 in. in diameter. If the pump makes 60 strokes per minute, how many gallons of water will be pumped per hour?

12. If a round steel rod 1-in. in diameter holds a load of 12,000 lb., how many pounds per square inch tensile stress exist in the rod? If the ultimate strength of this rod is 70,000 lb. per square inch, what fraction of the ultimate strength is represented by this load?

13. The strain, or stretch, of steel is proportional to the stress applied. If a rod 1 in. square and 30 in. long stretches 0.01 in. under a stress of 10,000 lb. per square inch, how much will it stretch under 15,000 lb. per square inch?

14. The moment of a force about an axis is the product of the force times the distance perpendicularly from the axis to the action line of the force. If a man exerts a tangential pull of 50 lb. on an airplane propeller 36 in. from the center of the shaft, what turning moment in pound-inches will he exert?

15. The pressure of water in pounds per square foot at any point beneath the surface equals the weight of the water above a square foot of area at that point. What will be the pressure in pounds per square foot at the bottom of a standpipe in which there is 50 ft. of water? If the standpipe is 24 ft. in diameter, what will be the total pressure on the bottom?

16. The pressure intensity in a fluid is equal in all directions at any point. What will be the pressure intensity against the side at the bottom of the standpipe in Prob. 15?

17. The pressure intensity in a fluid varies with the depth. What will be the pressure intensity at a point 12.5 ft. from the surface as compared to the pressure at a 75-ft. depth?

18. When a body slides on another, the friction resistance equals the pressure multiplied by the coefficient of friction, which for steel on steel is about 0.25. If a locomotive has a weight of 150 tons on the drivers, how much can it pull before slipping its wheels?

19. The work done by a force equals the product of the force times the distance through which it acts. How many foot-pounds of work are done by a man pushing a car 50 ft. if he exerts a force of 100 lb.?

20. The *mass* of a body in pounds is the amount of matter in it and equals its weight (attraction of the earth) in pounds divided by the gravitational constant, 32.1739 (approximately 32.2). How

many pounds mass in a body that weighs 200 lb.? [The student should distinguish between pounds weight (a force) and pounds mass (matter).]

21. The centrifugal force of a mass revolving about an axis equals the product of the mass times the tangential velocity (in feet per second) squared divided by the radius of revolution. $C = MV^2/R$. If a boxcar weighing 100 tons passes around a curve of radius 2,000 ft. at a velocity of 30 m.p.h., what will be the centrifugal pressure on the rails?

22. A certain cast-iron flywheel is 48 in. in diameter. If the portion of the rim tributary to one spoke weighs 200 lb., what is the pull in the spoke when the wheel is rotating at 300 r.p.m.? If the safe strength of cast iron is 5,000 lb. per square inch, what should be the diameter of the cylindrical spoke?

23. The energy (capacity to do work) of a moving body equals one-half the product of the mass times the velocity squared ($\frac{1}{2}MV^2$). How many foot-pounds of work will be required to stop an automobile weighing 1½ tons and moving 30 m.p.h.? (Velocity V must be in feet per second.)

24. How far would the above automobile roll if the rolling resistance is 3 per cent of its weight?

25. In a simple beam of rectangular cross section, the stress varies uniformly from a plane midway between top and bottom to a maximum compression at the top and maximum tension at the bottom. If in an 8- by 16-in. wooden rectangular beam, the stress is 1,200 lb. per square inch, at top and at bottom, what will be the stress 2 in. from the top and at 3 in. from the bottom?

26. A simple beam 24 ft. span carries 6,000 lb. and 2,000 lb. at points 10 and 18 ft., respectively, from the left end in addition to a uniform load of 200 lb. per linear foot. Compute the reactions.

27. A cantilever beam 10 ft. long supports a load of 1,000 lb. at the end and a uniform load of 200 lb. per foot. Compute the total moment of these loads at the support.

28. A steel rail 18 ft. long and weighing 540 lb. is carried by three men, two with a bar under the rail and the third at the end. Where should the bar be placed so that each man will carry one-third of the weight?

29. Suppose steel elongates 1/30,000,000 in. per inch of length for each pound per square inch tension. How much will a rod 1 in. in diameter and 10 ft. long elongate under a load of 12,000 lb.?

30. If cast iron will safely sustain 15,000 lb. per square inch in compression, what load can be placed on a circular cast-iron block 8 in. in diameter which has a hole 4 in. in diameter at the center?

31. A simple beam 10 ft. long and weighing 80 lb. carries a weight of 500 lb. 2 ft. from one end. What will be the reaction at each end?

32. The cylinder of a piston pump is 10 in. in diameter, and the stroke is 15 in. If the pump makes 60 strokes per minute, how many gallons of water will it pump per hour? 62 4 lbs / C ft.

1 gallon = 10 lb.

Related to Chemical Engineering

33. Representative sugar cane contains water 72 per cent, crystallizable sugar 15 per cent, uncrystallizable sugar 1 per cent, fiber 10 per cent, mineral ash 1 per cent, and other 1 per cent. How many tons of cane will be required to yield 1,000 lb. of sugar?

34. If good rubber contains 92 per cent rubber hydrocarbon and latex yields 35 per cent of this hydrocarbon, how many pounds of latex will be required per pound of finished rubber? C

35. Methane gas burns thus: $CH_4 + 2O_2 = CO_2 + 2H_2O$. How many pounds of oxygen will be required per pound of methane?

36. Portland cement typically contains silica (SiO_2) 23.0 per cent, iron oxide (Fe_2O_3) 2.5 per cent, alumina (Al_2O_3) 7.5 per cent, lime (CaO) 63.0 per cent, magnesia (MgO) 2.5 per cent, and sulphur trioxide (SO_3) 1.5 per cent. A certain limestone contains 54.5 per cent of CaO. How much of this stone will be required per 1,000 lb. of finished cement?

37. White lead pigment contains the carbonate, hydroxide, and oxide of lead in the following proportions: $PbCO_3$, 60.2 per cent; $2Pb(OH)_2$, 27.2 per cent; and PbO, 12.6 per cent. Calculate the amount of lead in 100 lb. of paint pigment.

38. Nitrocellulose, the base of cannon powder, is produced by digesting clean cotton in a mixed acid, *viz.*, nitric, 22 per cent; sulphuric, 63 per cent; and water, 15 per cent. Fifteen hundred lb. of the acid mix is required for 30 lb. of cotton. How many pounds of each acid will be required to nitrate 1,000 lb. of cotton?

39. Air is a mixture containing approximately by volume, N, 78.03 per cent; O, 20.99 per cent; CO_2, 0.03 per cent; and H, 0.01 per cent. What are the proportions by weight? How many pounds of each in 100 lb. of air?

40. A typical refining operation of crude petroleum gives in the "topping," straight gasoline, 32.0 per cent; "topped" crude, 67

per cent; gas and loss, 1 per cent. When "cracked" (heated above 1100°F. at 750 lb. per square inch pressure, thus breaking the heavier molecules), the yield of "topped crude" is gasoline, 47.8 per cent; residuum, 43.1 per cent; gas and loss, 9.1 per cent. What would be the topped and cracked yields of 1,000 lb. of crude?

41. When limestone ($CaCO_3$) is heated it breaks down into quicklime (CaO) and carbon dioxide (CO_2). How much lime should a ton of limestone yield?

42. In the manufacture of window glass, the charge of raw materials is sand 62.5 per cent, lime 18.75 per cent, and soda ash 18.75 per cent. How many pounds of each will be required to make a ton of glass?

43. An evaporator has condensing steam at 220°F. on one side of the heating surface and a sugar solution boiling at 214°F. on the other. If the rate of heat transfer and therefore of evaporation depends upon this temperature difference, what percentage increase of capacity of the evaporator would be obtained by putting the boiling liquid under a partial vacuum to lower its boiling point to 150°F.?

44. In a modern petroleum refinery, oil to be heated is pumped through a long pipe coiled in a furnace. If the rate of heating varies with the 0.8 power of the velocity at which it flows, what percentage would the heating rate be increased by doubling the velocity?

45. A rubber compound is analyzed by first extracting it with acetone. After evaporating the solvent, a dry residue is obtained which represents 4.3 per cent of the original sample and which includes all the sulphur. This extracted sample is found in turn to contain 3.15 per cent of sulphur. What is the percentage of sulphur in the original rubber compound?

Related to Civil Engineering

46. If the safe shear strength of rivets is 10,000 lb. per square inch, how many 1-in. rivets will be required to sustain in shear a force of 25,000 lb.?

47. If steel is twelve times as resistant as concrete, what compressive load will compress a 6-in. cylinder of concrete 12 in. long as much as 2,000 lb. will compress a steel bar 1 in. square and 12 in. long?

48. Steel contracts 0.000,0065 ft. per foot for each 1°F. drop in temperature and expands a like amount with a rise in temperature.

What will be the change in length of 33-ft. railroad rail if the temperature drops from 100°F. to 20° below zero?

49. The Empire State Building, being about 1,250 ft. high, has a steel frame. What will be the difference in the height on the two sides at noon when the south side averages 5° warmer than the north side?

50. A single load on a simple beam is 1,000 lb., and the reaction (uplift at the support) at one end is 300 lb. How much is the other reaction? Where is the load placed?

51. A bridge 240 ft. long carries a 200-ton locomotive with its center of gravity 80 ft. from one end. What will be the reactions at the abutments?

52. The rainfall on a water shed of 50 sq. miles is 2 in. in 24 hr. If 20 per cent runs off, how many cubic feet will flow down the stream from this rain?

53. A channel is 2 ft. wide at the bottom, 4 ft. wide at the top, and 2 ft. deep. If the average velocity of water in the channel when flowing full is 5 ft. per second, how many cubic feet of water will flow by a given point in 1 min.?

54. An 8-in. water main supplies two fire streams of 250 gal. per minute each. What will be the average velocity of water in the main? (1 gal. = 231 cu. in.)

55. The people of a city use for all purposes 100 gal. per capita (per person) per day. What will be the diameter of a cylindrical tank 20 ft. deep designed to hold a 2-day supply for a city of 10,000 population?

56. How many foot-pounds of work will be done per second if water is pumped 50 ft. high into a reservoir at the rate of 100 cu. ft. per second?

57. The energy of falling water equals the weight of the water multiplied by the height through which it falls. How many horsepower are represented by a stream of 500 cu. ft. per second falling over a precipice 50 ft. high? (1 hp. = 33,000 ft.-lb. of energy per minute.)

58. The rate of flow of water through purification filters, rapid type, is about 3,000 gal. per day per square foot of area. Consumption of water is about 100 gal. per capita per day. How many square feet of filter area will be required for a city of 50,000 population? How many filter units 12 by 20 ft. in plan?

59. If concrete costs \$7.00 per cubic yard and forms cost \$0.09 per square foot, what will be the cost of a concrete pier 6 by 18 ft. at the base, 3 by 18 ft. at the top, and 10 ft. high?

60. A tank, 60 ft. in diameter and 20 ft. deep, is supported on 8 steel columns. If the allowable stress in these columns is 12,000 lb. per square inch, compute the required cross section of the columns for this load when the tank is full of water.

61. Concrete is sometimes described as 1:2:4 mix, meaning that for one part cement there are two parts sand and four parts broken stone. If a certain job requires 100 cu. yd. of broken stone, how many cubic yards of sand and how many bags of cement (1 bag = 1 cu. ft.) will be required?

62. If crushed stone contains 40 per cent voids, how many cubic yards of crushed stone will 12 cu. yd. of solid stone yield when crushed?

63. The length of the main span of the Metropolis bridge (the longest simple span) is 722 ft. If the coefficient of expansion of steel is 0.000,0065, how much will this span change in length for a variation in temperature from 10°F. below zero to 90° above zero?

64. If the sag of the cables of the Detroit suspension bridge is 1 in 9, the span being 1,850 ft., what will be the difference between the elevation of the cables at the tower and at mid-span?

65. Each cable of the Detroit suspension bridge consists of 37 strands having 218 wires in each strand. Number 6 wire, 0.195 in. in diameter was used. The maximum strength of this steel wire is 215,000 lb. per square inch. What maximum load would each cable carry? The stress used in the design was 76,000 lb. per square inch. What was the factor of safety used?

66. The pressure per square foot of wind against a surface is approximately equal to $0.003V^2$, where V is the velocity of the wind in miles per hour. What will be the pressure on a building 80 by 50 ft. caused by a hurricane at 100 m.p.h.?

67. The pressure per square foot of a jet of water against a flat surface is approximately $1.93V^2$, where V is the velocity in feet per second. What will be the pressure intensity of a jet 3 in. in diameter against a stationary flat vane of a wheel if the jet has a velocity of 50 ft. per second?

68. The four cables of the George Washington bridge when fully loaded carry 261,400,000 lb. Each cable contains 61 strands of 434 wires each. Each wire is 0.196 in. in diameter. What will be the

pull on each wire in pounds per square inch? If the stretch of steel is 1/30,000,000 in. for each pound per square inch and the cables are 5,160 ft. long, what will be the total elongation of the cable under full load?

69. If the rolling resistance of freight trains is 5 lb. per gross ton on straight level track and 20 lb. additional for 1.0 per cent grade, what will be the total locomotive draw bar pull required for a train of 80 cars weighing 20 tons each and carrying 80 tons load each up a 1.5 per cent grade?

70. If the locomotive pulls this train up the grade at 15 m.p.h., what horsepower is developed?

71. What is the cost per mile of a highway concrete slab 6 in thick and 18 ft. wide if the concrete costs $1.50 per square yard?

72. If the wind resistance of an automobile varies (approximately) as the cube of the speed, compare the resistance of a car at 60 m.p.h. and at 20 m.p.h.

73. If it costs $30,000 to cut a highway through a hill, thereby saving 1½ miles distance, and there are 1,000 vehicles daily along the road, and if saving a vehicle mile is worth $0.10, will the annual saving equal the interest on the cost?

74. By adding $200,000 in reducing grades on a certain division of a railroad, $8,000 per year can be saved in operating expense. Will it be economical to make the added expenditure?

75. Side slopes of earth cuts and fills are usually 1½ to 1, meaning 1½ ft. horizontal to 1 ft. vertical. How many cubic yards of excavation in a cut 100 ft. long, 6 ft. deep, and 20 ft. wide on the bottom?

76. A wooden trestle costing $10,000 will have a life of 10 years. How much could be economically spent for a steel bridge that would last 30 years, assuming maintenance to be the same?

77. How much can a railroad afford to pay for treating ties that cost $1.25 each in place if the treatment will make their life 12 years instead of 7 years?

78. In building a railway across a ravine, the railway may be carried on a high embankment or on a trestle. The embankment costs $100,000 and is permanent and essentially without maintenance cost; the bridge will cost $60,000, will last 30 years, and will require $800 per year for painting and other maintenance. What will be the annual cost of each scheme (interest at 4 per cent), and which will be the more economical?

79. Which of the two methods of handling material is the more economical: to use a gasoline engine costing $800 which will last 10 years and require $1 per day for fuel and maintenance, or to employ two additional men at $3 per day? (Interest 4 per cent.)

80. If wet concrete exerts a pressure of 75 lb. per square foot at a depth of 1 ft. and the pressure increases with the depth, what will be the intensity of pressure at the bottom of a column form 15 ft. high? If the column is 2 ft. square, what will be the total pressure on one side?

Related to Electrical Engineering

81. The power for a direct-current circuit (in watts) equals the current flowing (in amperes) multiplied by the potential (in volts). (Watts = amperes × volts.) If in charging an automobile battery a 10-amp. current at 6.5 volts flows into the battery for 8 hr., how many kilowatt-hours of energy have been stored in the battery?

82. For direct-current circuits the current flowing (in amperes) equals the potential (in volts) divided by the resistance (in ohms). Amperes = volts/ohms.

The resistance of a No. 10 gage copper wire is 0.0009972 ohm per foot. What current will flow through a 5-mile circuit of this wire if the current is generated at 110 volts?

83. In a divided circuit, the resistances of the two branches are 5 and 7 ohms, respectively. The total current is 24 amp. What current will flow in each branch? (The current is divided inversely proportional to the resistances.)

84. The power loss in watts in a transmission line equals the square of the amperes of current multiplied by the ohms of resistance. How much power will be lost in transmitting 50-amp. current at 6,600 volts a distance of 10 miles over a copper wire having a resistance of 0.545 ohm per mile?

85. A street-car wheel has a diameter of 33 in., and the gear ratio between the motor and axle is 68:14. What is the motor speed in revolutions per minute when the car is running 30 m.p.h.?

86. A generator is supplying 1,200 amp. to a trolley at 600 volts. How much power is being delivered in kilowatts? (Watts = amperes × volts.)

87. If the efficiency of the generator is 92 per cent, that of the transmission line is 96 per cent, and that of the motor on the car is

90 per cent, what proportion of the power delivered to the generator is actually applied in driving the car?

88. If the velocity of voice transmission over a telephone is 175,000 miles per second how long will it take a word to travel from New York to San Francisco (3,000 miles)?

89. The velocity of propagation of an electromagnetic wave is expressed as the product of the wave length (in meters) and the frequency (cycles per second). If the velocity of these waves is 300,000,000 meters per second and the frequency of television station W9XK is 2,050 kc., what is the wave length?

90. If sound travels 1,100 ft. per second in air and 186,000 miles per second as an electric impulse, how far would sound travel through the air in the time required for the voice to travel 1,000 miles by radio?

91. The velocity of sound in copper is 11,700 ft. per second. How much faster does sound travel as an electric impulse through copper wire than as a sound wave?

92. If the frequency of calls at a switchboard at the busiest time is 4.5 times the average, how many calls will come in the busiest 5 min. if the total is 4,200 in 24 hr.

93. Compare the cost of illumination per candle power with gas and electricity based on the following data: A gas jet using 5 cu. ft. per second of gas per hour produces a 20-cp. light; gas cost $1.10 per 1,000 cu. ft. A 16-cp. Mazda electric light consumes 40 watts costing $0.09 per kilowatt-hour.

94. If the potential at one end of a mile of No. 10 gage copper wire is 220 volts and the resistance is 0.001 ohm per foot, what will be the voltage at the other end with 5 amp. of current flowing?

95. The resistance (resistivity) of a wire varies inversely with the area of cross section and directly with the length. A No. 10 copper wire 0.1 in. in diameter has a resistance of approximately 1 ohm per 1,000 ft. What will be the total resistance of a mile of wire 0.365 in. in diameter?

96. The conductance (conductivity) is the reciprocal of resistance, the unit being one mho (ohm backward). The conductance of aluminum is 64.6 per cent that of copper. What diameter of aluminum wire will have the same conductance as a No. 10 copper wire?

97. All electric waves travel at a velocity of 300,000,000 m. per second; hence the frequency equals 300,000,000 divided by the wave length in meters. What will be the frequency of a radio wave of

10,000 m.? What will be the length of a radio wave of 1,000 kc.?

98. Compute the power in watts of a direct-current motor with 100 ohms resistance operating under a 50-amp. current. Power in watts equals amperes^2 $\times$ ohms. What is the horsepower? (1 hp. equals 0.746 kw.)

99. If the luminosity of an electric light varies inversely as the square of the distance from the light bulb (why), how will the illumination on your study table at 4 ft. compare with that at 6 ft. from the bulb?

100. If a 1 per cent drop in voltage causes a 3 per cent drop in luminosity, how will the candle power of a 60-cp. bulb at the end of a mile of copper No. 10 wire compare with that of a like bulb at the generator, current at 220 volts?

101. The mechanical equivalence of light is 1 watt equals 668 lumens. A candle-power intensity is produced by 1 lumen of light per square foot of surface. How many lumens are represented by a 40-watt bulb? What would be the candle-power intensity 5 ft. away?

102. A Mazda 40-watt lamp costs 10 cts. and has a life of 1,000 hr. If electrical energy costs 9 cts. per kilowatt-hour, what will be the cost of operating a 40-watt light in your room 6 hr. per day for 30 days?

103. What will be the cost of energy used to operate a ¼-hp. motor on a washer for 2 hr.? (1 hp. = 746 watts.)

104. A $300 electric motor that is obsolete but good for 10 years more service has a salvage value as scrap of $30. Will it be economical to install a new $300 motor that will last 20 years and will do the same work using 500 watts less power of electric energy that costs $0.06 per kilowatt-hour? The motors operate continuously.

Related to Mechanical Engineering

105. If a boiler using coal of 11,850 B.t.u. per pound has losses in ashes of 450 B.t.u., radiation into air 220 B.t.u., and in flue gases 2160 B.t.u. per pound of coal burned, how many B.t.u. are actually utilized in steam, and what is the efficiency of the boiler?

106. Robert Boyle (London) experimenting with an air pump discovered that in an expanding gas at constant temperature the pressure varies inversely with the volume. If the pressure in a 3-ft. sphere filled with gas is 100 lb. per square inch, what will be the

pressure intensity if the same gas occupies a 9-ft. sphere? What will be the total internal pressure in the two cases?

107. Robert Hooke, Boyle's assistant, discovered that for a spring or other elastic body, the stretch is proportional to the load applied. If 1,000 lb. compresses a car spring ¾ in., what load will compress it 2½ in.?

108. If a torque of 500 in.-lb. (50 lb. on an arm of 10 in.) twists a rod through an angle 1°15′, what will be the total angle of twist if a force of 75 lb. is similarly applied on an arm of 20 in.?

109. Jaques Charles, a French mathematician, experimenting with balloons (1787), discovered that if the volume of a gas is kept constant the pressure of a gas varies directly with the absolute temperature measured from absolute zero (−459.6°F.). If a gas in a tank exerts a pressure of 100 lb. per square inch at 50°F., what will be the pressure if heated to 100°F.?

110. The crushing strength of ball bearings is proportional to the square of the diameter. If a bearing with balls ½-in. in diameter will safely sustain 9,000 lb., what load will a similar bearing with ⅝-in. balls sustain?

111. A gasoline engine with a flywheel 36 in. in diameter operating at 400 r.p.m. exerts a pull of 200 lb. on the belt. What horsepower is developed?

112. If steam in the cylinder of an engine is at 280°F. and 200 lb. per square inch pressure at the beginning of the stroke when occupying 0.2 cu. ft., what will be the pressure at the end of the stroke when the volume is 1.0 cu. ft. and the temperature 220°F.?

113. In a certain gear train, a 3-in. gear wheel drives a 12-in. gear wheel. If the center of contact of the gears is ½ in. inside the periphery of the gears, what will be the speed of the larger gear when the smaller is rotating at 200 r.p.m.?

114. If a round steel piston rod is subjected to a load of 24,000 lb., and the safe working stress in this member is 10,000 lb. per square inch, what should be the diameter of the piston rod?

115. The crank arm of a crankshaft in a gasoline engine is 3 in., and the crank rotates at 300 r.p.m. How fast will the piston travel at its greatest speed? At what point will this occur? At what point will the piston speed be zero?

116. A shaft 3 in. in diameter rotates at 300 r.p.m. If the journal friction is 2 lb., how many foot-pounds of work are done per minute overcoming friction? What fraction of a horsepower?

117. A leather belt connects a 24-in. pulley to a 6-in. pulley. If the former rotates 200 r.p.m., what will be the speed of the latter if the belt slippage is 3 per cent?

118. How far does a point on the foregoing belt travel in 1 sec.?

119. If Pocahontas coal contains 14,000 heat units (B.t.u.) per pound, and it requires 1198.5 heat units to evaporate 1 lb. of water under 200 lb. boiler pressure, how many pounds of coal will be required to evaporate 34,500 lb. of water per hour in a boiler that is 75 per cent efficient? (1 B.t.u. is the amount of heat required to raise the temperature of 1 lb. of water 1°F.)

120. If a simple condensing engine requires 32 lb. of steam per horsepower-hour, what power engine will the foregoing boiler supply?

121. If 1 lb. of a given coal contains 10,000 heat units and 1 kw.-hr. of energy requires 3,412 heat units, how many tons of coal are required per hour for a 50,000-kw. steam plant if the over-all efficiency is 22 per cent?

122. If a pound of fuel oil contains 19,500 heat units and a Diesel engine has an over-all efficiency of 32 per cent, how many gallons should a storage tank hold for a 7-day run of a 500-hp. engine, when 1 hp. requires 2,546 heat units? (Oil weighs 7 lb. per gallon.)

123. If the explosion pressure in a gasoline engine having a 6-in. bore is 100 lb. per square inch, what is the total force exerted on the piston?

124. If a theater seats 2,000 people and 30 cu. ft. of air are required per minute per person for ventilation, how large an air pipe will be required if the air flows 20 ft. per second? If 1½ grains of moisture are required per cubic foot of air, how many gallons of water are required per hour?

125. A certain icebox gains heat from the surrounding air at the rate of 400 heat units per hour. If the heat of melting of ice is 144 heat units per pound, how long will 100 lb. of ice last in the box?

126. A steam turbine is to rotate at 3,600 r.p.m., and the allowable peripheral speed of the rotor blades is 400 ft. per second. What should be the tip diameter of the rotor?

127. A 50,000-kw. steam turbine has a steam consumption of 9 lb. of steam per kilowatt-hour. If the cooling water for the condenser enters at 80°F. and leaves at 100°, and the heat absorbed by the water is 990 heat units per pound of steam condensed, how many pounds

of cooling water are required per hour? (1 lb. of water absorbs 1 heat unit for each degree change in temperature of the water.)

128. An airplane weighing 2,400 lb. can deliver 240 hp. (1 hp. = 33,000 ft.-lb. of work per minute.) If all this power could be used in climbing, in what time could the plane climb to 10,000 ft. if the friction of the atmosphere is 240 lb.?

129. If a lathe costing $4,200 will last 20 years, what is the annual depreciation charge? What is the interest charge at 6 per cent?

130. What annuity at 6 per cent will be sufficient to replace this machine in 20 years?

131. By building a power plant at $100,000, a manufacturing company can furnish its own power, 1,000 kw., at 1 ct. per kilowatt-hour operating cost. The plant runs 8 hr. per day 6 days per week. Depreciation of the plant is taken at 5 per cent. It can buy power from a public utility at 3 cts. per kilowatt-hour. Which will be the more economical?

Related to Mining Engineering and Metallurgy

132. The atomic weight of aluminum is 26.97 and that of oxygen is 16. Calculate the amount of aluminum in a ton of the ore alumina (Al_2O_3).

133. The atomic weight of iron is 55.84 and of oxygen, 16. Calculate the amount of iron in a ton of hematite ore (Fe_2O_3); in a ton of magnetite ore (Fe_3O_4); in a ton of limonite ore (FeO_3); in a ton of pyrite FeS_2 (atomic weight of sulphur is 32.06); in a ton of siderite ($FeCO_3$) (atomic weight of carbon is 12).

134. If the dip of a vein of coal is 1.5 per cent from its outcrop on level ground, what will be the depth of the vein 2,500 ft. from the outcrop? How many foot-pounds of work will be performed per ton lifted through that height?

135. If a placer monitor uses 450 gal. per minute, how many monitors can be supplied by a mountain brook flowing 5 cu. ft. per second?

136. Pig iron contains about 95.8 per cent Fe, 3.5 per cent C, 1 per cent Si, 0.15 per cent S, 0.05 per cent P, 0.5 per cent Mn. Compute the weight of each element in a ton of pig.

137. *Cementite* (Fe_3C) is one of the crystal constituents of steel. Compute the percentages of iron and carbon in cementite.

138. *Pearlite,* another crystal constituent of steel, contains 7 parts of *ferrite* (pure iron) to 1 part of *cementite.* Compute the percentages of iron and carbon in pearlite.